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SYSTEMS ENGINEERING CAPSTONE REPORT

EXAMINING OPERATIONAL AND DESIGN EFFECTS OF MH-60S WITH ENHANCED WEAPON SYSTEMS IN ANTI SURFACE WARFARE MISSIONS

by

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September 2018

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13. ABSTRACT (maximum 200 words)

The United States Navy (USN) employs distributed maritime operations (DMO) by increasing the offensive capabilities of its surface fleet, known as adaptive force packages (AFP). One component of DMO, rotary wing aircraft supporting anti-surface warfare (ASuW), lacks a long-range weapon capability. The purpose of this project was to determine the benefit to DMO of providing the MH-60S fleet with a long-range standoff weapon capability, determine the feasibility of integrating a long-range missile (LRM) onto the MH-60S, and determine the capabilities required of that weapon system by answering the following main two project questions: How can the USN use the MH-60S in greater capacity in DMO for ASuW missions, and what is the current trade space of long-range ASuW weapons that can be added to the MH-60S to affect the DMO environment? A discrete event model was created to simulate ASuW scenarios within DMO and to evaluate the effects to the established measures of effectiveness and performance. Analysis shows that the addition of LRMs provides an increased capability and reduces the overall percentage of threats to the AFP. An analysis of alternatives revealed only three available LRMs are feasible for the USN's consideration.

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ABSTRACT

The United States Navy (USN) employs distributed maritime operations (DMO) by increasing the offensive capabilities of its surface fleet, known as adaptive force packages (AFP). One component of DMO, rotary wing aircraft supporting anti-surface warfare (ASuW), lacks a long-range weapon capability. The purpose of this project was to determine the benefit to DMO of providing the MH-60S fleet with a long-range standoff weapon capability, determine the feasibility of integrating a long-range missile (LRM) onto the MH-60S, and determine the capabilities required of that weapon system by answering the following main two project questions: How can the USN use the MH-60S in greater capacity in DMO for ASuW missions, and what is the current trade space of long-range ASuW weapons that can be added to the MH-60S to affect the DMO environment? A discrete event model was created to simulate ASuW scenarios within DMO and to evaluate the effects to the established measures of effectiveness and performance. Analysis shows that the addition of LRMs provides an increased capability and reduces the overall percentage of threats to the AFP. An analysis of alternatives revealed only three available LRMs are feasible for the USN's consideration.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access/area-denial
AFP	adaptive force package
APKWS	Advanced Precision Kill Weapon System
A_o	operational availability
AoA	analysis of alternatives
ARG	amphibious readiness group
ASCM	anti-ship cruise missile
ASuW	anti-surface warfare
BLOS	beyond line of sight
CG	guided missile cruiser
CONOPS	concepts of operation
CRUDES	guided missile cruiser and destroyer
CSG	carrier strike group
CSW	crew served weapon
CVN	nuclear aircraft carrier
DDG	guided missile destroyer
DL	distributed lethality
DMO	distributed maritime operations
DoDAF	Department of Defense Architecture Framework
DOE	design of experiments
DOTmLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy
FAC	fast attack craft
FIAC	fast inshore attack craft
FFBD	functional flow block diagram
FLIR	forward looking infrared radar
HELLFIRE	Helicopter Launched Fire-&-Forget missile
HSC-6	Helicopter Sea Combat Squadron Six

HSCWP	Helicopter Sea Combat Wing Pacific
ISR	intelligence, surveillance and reconnaissance
km	kilometer
LCS	littoral combat ship
LHA/D	amphibious assault landing helicopter assault/dock
LRM	long-range missile
MaxTTR	maximum time to repair
MBSE	model-based systems engineering
MOEs	measures of effectiveness
MOPs	measures of performance
MTBF	mean time between failure
MTS	multi-spectral targeting system
MTTR	mean time to repair
NAVAIR	Naval Air Systems Command
nm	nautical miles
NPS	Naval Postgraduate School
NSM	Naval Strike Missile
PSSK	probability of single shot kill
SE	systems engineering
Std Dev	standard deviation
TCDL	Tactical Common Data Link
USN	United States Navy
WEZ	weapons engagement zone

EXECUTIVE SUMMARY

The purpose of this capstone report is to determine the benefit to distributed maritime operations (DMO) by providing the MH-60S fleet with a long-range standoff weapon capability. The United States Navy (USN) employs DMO by increasing the offensive capabilities of its surface fleet, to include cruisers, destroyers, littoral combat ships, amphibious ships, and logistics ships, and "employing them in dispersed offensive formations" (Fanta, Gumataotao, and Rowden 2015, under "Control 'Can No Longer Be Assumed'") known as adaptive force packages (AFP). This project focuses on anti-surface warfare (ASuW), specifically, the insertion of long-range ASuW weaponry into the arsenal of rotary-wing aircraft currently stationed aboard many ships already deployed and operating in AFPs. The goal of this new capability is to further the tenets of DMO by projecting another offensive, long-range ASuW capacity as a complement to carrier strike group/amphibious readiness group aircraft-based ASuW systems. The primary functions of the MH-60S include special operations forces insertion, ASuW, personnel recovery, search and rescue, and vertical replenishment. Currently, the MH-60S supports ASuW missions but does not have long-range, beyond-line-of-sight weapon capabilities.

This capstone project addresses the following questions:

- How can the USN use the MH-60S in greater capacity in DMO for ASuW?
    - Does the MH-60S, equipped with long-range ASuW weapons, provide added capability to the DMO environment relative to its assumed baseline of loadout of two guided missile destroyers, one guided missile cruiser, one littoral combat ship, one amphibious ship, four MH-60S helicopters, and two MH-60R helicopters?
- What is the current trade space of long-range ASuW weapons that can be added to the MH-60S to affect the DMO environment?
    - How is operational effectiveness and high-level cost impacted?
    - What long-range ASuW weapon systems can the MH-60S utilize?

Mission success is defined as the ability of the MH-60S, equipped with a long-range missile (LRM), to destroy enemy targets while remaining outside the weapons engagement zone of the enemy. To evaluate the effectiveness of adding the LRM-equipped MH-60S to the AFP, we developed a discrete event simulation model depicted in Figure 1. The model simulates an ASuW scenario with the MH-60S equipped with an LRM but does not simulate any particular AFP configuration. The simulation begins after the MH-60S aircraft have launched from the AFP ships. The model assumes that the AFP will contain additional MH-60S aircraft that can be leveraged for the long-range capability, so variances in ship types within the AFP will not vary the results or analysis. For enemy threats, the Fast Attack Craft (FAC) was modeled after the Iranian Navy's Thondar class missile boat. The Fast Inshore Attack Craft (FIAC) threat was modeled after the Islamic Revolutionary Guard Corps Navy's Bladerunner 51.

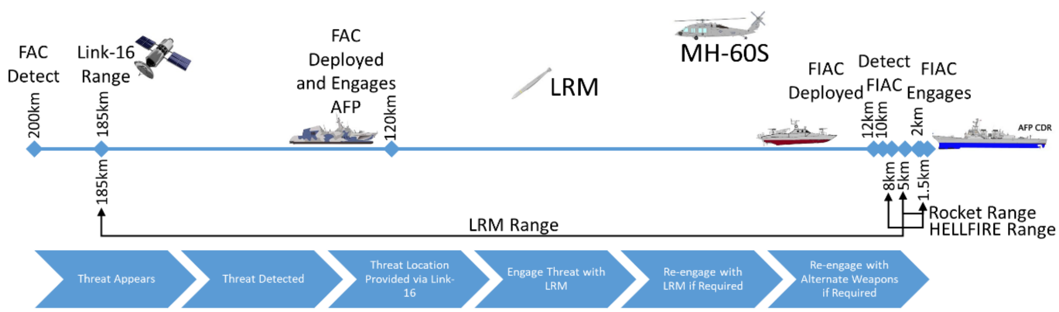

Figure 1. ASuW Scenario for ExtendSim Modeling. Adapted from Davis (2017).

Using a design of experiments analysis, the statistically significant simulation input factors were determined and refined. The baseline simulation was the ASuW scenario of the MH-60S with a loadout of only HELLFIRE missiles and 2.75" short-range rockets. We compared these results to simulation results of the MH-60S equipped with varying numbers of LRMs. Analysis of simulation output data showed only three significant input factors: number of FACs, number of total LRMs in the AFP, and number of FIACs. With this knowledge, additional analysis focused on significant output responses from the model: threats to the AFP, C-802 engagements, FACs destroyed, and FIACs destroyed.

The response analysis indicates that the use of an MH-60S equipped with LRMs in support of an ASuW mission provides an increased capability within DMO and reduces the overall percentage of threats to the AFP. The analysis also shows that 100% of FIAC threats are destroyed in all scenarios, including the baseline; therefore, all LRMs should be reserved for FAC threats only. The increase in effectiveness of adding LRMs is relatively consistent from zero to four LRMs; however, the impact to effectiveness of bringing the total number of LRMs up to six is only beneficial when significant quantities of FAC threats are presented. If the enemy deploys five or fewer FACs, a total of four LRMs is sufficient for the AFP to defend itself. However, if the enemy deploys more than five FACs against the AFP, then a total of six LRMs is required for the AFP to best defend itself. Additionally, the analysis showed that the LRM's capability parameters, maximum range, minimum range, velocity, and probability of hitting an enemy ship, are not significant in this model, so an analysis of alternatives (AoA) of available LRMs was conducted. The AoA revealed only three feasible solutions for the USN's consideration: the Norwegian Naval Strike Missile, Turkish SOM-A, and the Israeli Delilah HL.

While this data shows that the addition of the MH-60S with LRM increases the effectiveness of the AFP, further research is recommended to quantify the impact of the assumptions that were made as part of this project. Specifically, the impact of supporting systems and infrastructure is not fully understood. The simulation assumes that systems, such as data link (i.e., Link-16 or TCDL) and intelligence, surveillance and reconnaissance platforms, are functioning and available at all times. Further analysis is needed to understand the impact cost of integrating and supporting an MH-60S fleet with LRMs. The further research suggested in this report will enable the USN to make more informed decisions on the development of an MH-60S fleet equipped with LRMs.

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I. INTRODUCTION

A. BACKGROUND

Distributed maritime operations (DMO), sometimes referred to as distributed lethality (DL), is the United States Navy's (USN) combat doctrine with the objective to cause the enemy to shift its resources from offensive to defensive to counteract the USN's increased sea surface footprint. This approach to maritime operations intends to force the enemy to reallocate its "critical and limited resources across a larger set of defended targets, thereby improving our operational advantage" (Fanta, Gumataotao, and Rowden 2015, under "Force Shift"). DMO is a paradigm shift from defensive operations to offensive operations. It enables the USN to counteract the enemy's anti-access/area-denial (A2/AD) weaponry, and it increases the USN's freedom to maneuver in patrolled waters (Fanta, Gumataotao, and Rowden 2015).

The USN employs DMO by increasing the offensive capabilities of its surface fleet, to include cruisers, destroyers, littoral combat ships, amphibious ships, and logistics ships, and "employing them in dispersed offensive formations" (Fanta, Gumataotao, and Rowden 2015, under "Control 'Can No Longer Be Assumed'") known as adaptive force packages (AFP). Adaptive force packages can be deployed together as a unit as well as uniting specific assets from several deployed units within a desired proximity to a threat. The surface assets in a typical AFP employ a number of air assets to include fixed-wing, rotary-wing, and a command, control, communications, computers, intelligence, surveillance and reconnaissance platform from an already deployed carrier strike group (CSG) or amphibious readiness group (ARG). Adaptive force packages in the DMO architecture are responsible for maintaining localized sea control through area defense and self-defense, force projection, area command and control, and self-sustainment (Fanta, Gumataotao, and Rowden 2015).

One component of DMO, and the focus area of this research, is anti-surface warfare (ASuW), specifically, the insertion of long-range ASuW weaponry into the arsenal of rotary-wing aircraft currently stationed aboard many ships operating in AFPs. The goal of this new capability is to further the tenets of DMO by projecting another offensive, long-range ASuW capacity as a complement to CSG / ARG aircraft-based ASuW systems.

First deployed in August 2002, the MH-60S "Seahawk" helicopter is a single main rotor, twin engine, multi-mission helicopter manufactured by Sikorsky Aircraft Corporation. The primary functions of the MH-60S include special operations forces insertion, ASuW, personnel recovery, search and rescue, and vertical replenishment. Naval Air Systems Command (NAVAIR) PMA-299 manages the fleet of 275 MH-60S aircraft currently operating in the USN. The MH-60S maximum speed is 180 knots with a standard range of 245 nautical miles (nm), ceiling height of 13,000 feet, and a load capacity of 9,000 kilograms (kg). The MH-60S is equipped with a number of communications and survivability mission systems including Link-16, Tactical Common Data Link (TCDL), and a Multi-spectral Targeting System (MTS) that includes forward looking infrared radar (FLIR). The joint communications systems, Link-16 and TCDL, generically termed "Link-16" for this project, allow communications among many assets across different platforms including fixed-wing, rotary-wing, and surface ships. (Department of the Navy [USN] 2015; Naval Air Systems Command [NAVAIR] 2016a, 2016b)

The MH-60S Block 3B, with the proper Armed Helo mission kit items installed, is capable of performing various tactical maritime and land-based missions and is a staple in various ASuW missions within DMO. Currently, the MH-60S employs a variety of short-range (less than 10nm) weapons for use against soft targets or minimally hardened targets, such as small surface craft threats. Defenders of these targets typically use small-arms fire or short-range, surface-to-air missiles. To accomplish this short-range ASuW mission, crew served weapons are installed in the cabin of the aircraft, and the aircraft pilot and co-pilot's external weapon systems are each outfitted with an M-299 missile launcher. Using the M-299 launchers, the MH-60S can be configured in a variety of tactical weapon system configurations. These configurations include:

- Up to eight AGM-114B/K/M/N Helicopter Launched Fire-&-Forget (HELLFIRE) missiles,

- Up to two crew serviced A/A29E-27 20mm gun systems,

- Up to two crew serviced GAU-21 0.50-caliber machine guns,
- Up to two crew serviced M240D (7.62mm) machine guns,
- Up to 38 LAU-61C/A 2.75-inch unguided rocket system, and
- Up to 38 Advanced Precision Kill Weapon System (APKWS) 2.75-inch guided rockets. (USN 2015, 1–2 and 1–3)

These munitions, in combination with data link, enable the MH-60S to successfully execute dynamic targeting and short-range threat engagement within the ASuW mission area.

B. PROBLEM DEFINITION AND PURPOSE

The primary purpose of this capstone project is to determine the benefits of integrating a long-range standoff weapon system to the MH-60S in the DMO environment. While the MH-60S currently supports ASuW missions, it lacks a long-range, beyond line of sight (BLOS) standoff capability. Exploring the long-range standoff weapon system capabilities necessary to be effective in the DMO environment is an initial step in defining this shift in the USN operations. It sets the stage for further research into currently fielded weapon systems that meet the required capabilities. The secondary purpose of this project is to determine if any single long-range standoff weapon system or combination of weapon systems meet the necessary capabilities for improving the MH-60S in its ASuW mission. One output of this project is a combat simulation using a design of experiments (DOE) to show the trade space for a long-range BLOS standoff capability. Additionally, several Department of Defense Architecture Framework (DoDAF) compliant operational and system views provide a comparison of how the MH-60S operationally fits into the DMO versus the current operational employment. The views depict the basis for the simulation and system architecture modifications.

The MH-60S is the focus of this research; however, recommendations regarding a long-range missile integration may also apply to the MH-60R. Integration on the MH-60R would need to take into account the differences between the MH-60S and MH-60R, such as size, weight and power requirements as well as the organic sensors onboard the MH-

60R, and consideration of the MH-60R is outside the scope of this project. Suggested future research studies outside the scope of this project are a capability study on weapon systems under development for future implementation into the USN arsenal, a capability study on targeting sensors to support the BLOS capability, a manpower analysis on the addition of the BLOS capability, and a capability study on the addition of unmanned aerial vehicles to the AFP construct.

The Navy would like to identify the benefits to DMO of providing the MH-60S fleet with a long-range standoff weapon capability, to determine the feasibility of integrating a BLOS ASuW weapon system onto the MH-60S, and to determine the capabilities required of that weapon system. It is expected that Helicopter Sea Combat Squadron (HSC)-6 and Helicopter Sea Combat Wing Pacific (HSCWP) will use this data as evidence of an operational requirement at the naval aviation readiness group and request funding to support the development of a new system or integration of a fielded system to meet this capability. Additionally, we expect that NAVAIR will use this information in future research for added capability planning for the MH-60 family of helicopters. In the course of this capstone project, we address the following questions:

- How can the USN use the MH-60S in greater capacity in DMO for ASuW missions?
    - Does the MH-60S, equipped with long-range ASuW weapons, provide added capability to the DMO environment relative to its assumed baseline of loadout of two guided missile destroyers, one guided missile cruiser, one littoral combat ship, one amphibious ship, four MH-60S helicopters, and two MH-60R helicopters?
- What is the current trade space of long-range ASuW weapons that can be added to the MH-60S to affect the DMO environment?
    - How is operational effectiveness and high-level cost impacted?
    - What long-range ASuW weapon systems can the MH-60S utilize?

C. SYSTEMS ENGINEERING PROCESS

This capstone project uses standard systems engineering (SE) principles and processes to analyze the effects of equipping the MH-60S with a long-range, BLOS capability for ASuW missions. The project uses a modified Vee SE process model, as shown in Figure 1, which is adapted from the Vee model described in the Naval Postgraduate School (NPS) *A Guide for Systems Engineering Graduate Work: How to Write Well and Make Your Critical Thinking Visible* (Naval Postgraduate School 2017).

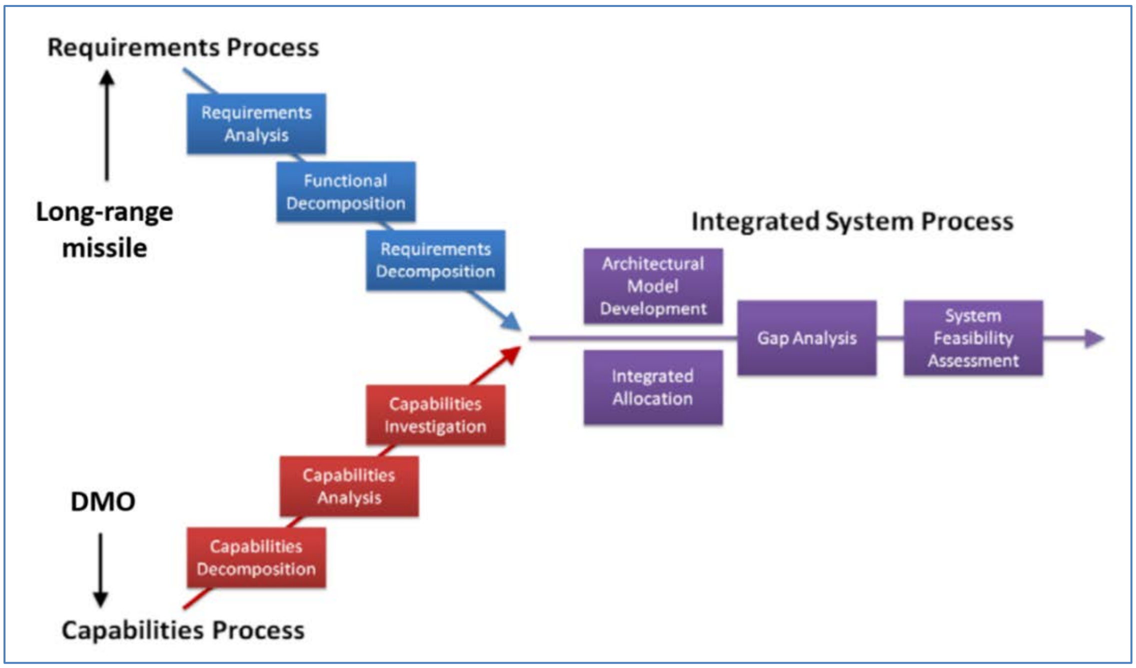

Figure 1. Project Systems Engineering Process. Adapted from Naval Postgraduate School (2017)

To investigate the capabilities necessary for the MH-60S, a model-based systems engineering (MBSE) approach is used to investigate concepts of operations (CONOPS) and operational functions required for the MH-60S helicopter variant in current and future naval operational scenarios. In his lecture on April 4, 2018, entitled "Model-Based Systems Engineering De-Mystified," Dr. Warren Vaneman described MBSE as a formalized process that utilizes DoDAF products to support system design and analysis by depicting traditional systems engineering processes using visual models and views. Using the

DoDAF products, the system is decomposed from operational to system views and then further refined into functional flows. These functions, coupled with their relevant technical parameters (derived from publicly available MH-60 and weapon system information to ensure the widest dissemination of this research), are used to develop a technical model of the system under investigation. A discrete event simulation was then used to analyze various capability solutions for a long-range, BLOS offensive strike capability for the MH-60S to be used in the DMO environment. The focus is to determine potential trade space considerations by assessing the operational effectiveness of adding the engagement of BLOS targets to the MH-60S.

II. CAPABILITIES ANALYSIS

A. STAKEHOLDER ANALYSIS

A stakeholder analysis was conducted to determine the needs, wants, and desires of the relevant organizations, people, and entities interested in a long-range missile (LRM) capability in the MH-60S. This analysis was conducted by directly interviewing the stakeholders, reviewing previous NPS research into DMO and the closely related DL, and researching documented issues within DMO.

The MH-60S has many stakeholders with different needs, wants, and desires for ASuW; therefore, stakeholders must be prioritized. The stakeholders were given a priority from one to four, with one being the highest and four being the lowest. For this project, the focus is on priority one and two stakeholders in the operational life cycle stage of the MH-60S, specifically within the ASuW mission during DMO. Priority one was given to stakeholders with direct influence over the operational use, deployment, and budgetary planning for the MH-60S. For the operational stage, PMA-299, HSC-6, HSCWP and AFP commanders were designated as priority one stakeholders. Priority two was given to stakeholders who are required to use and maintain the MH-60S. For the operational stage, MH-60S pilots, crew, maintenance officers, and logistics personnel were designated as priority two stakeholders. Priority three was given to stakeholders with direct influence on the design of the system. NAVAIR's airworthiness authority, Sikorsky Aircraft, and missile manufacturers were designated as priority three stakeholders. And lastly, priority four was given to stakeholders without direct influence of any aspect of the system. Allied forces and taxpayers were designated as priority four stakeholders. Collected inputs from stakeholders are captured in Table 1; however, the needs, goals, and concerns of the priority one stakeholders were the main focus of this project. Future research regarding the integration and implementation of the long-range strike capability will require more extensive analysis to address the needs, goals, and concerns of the priority two, three, and four stakeholders.

Table 1. Stakeholder Analysis (Continued on Next Page)

Stakeholder	Priority	Need(s)	Goal(s)	Concern(s)
Helicopter Sea Combat Squadron (HSC)-6	1	Fill capability gap by adding long-range strike capability to MH-60S in anti-surface warfare (ASuW)	Complete missions using MH-60S	Operational/capability overlap between systems
Helicopter Sea Combat Wing Pacific (HSCWP)	1	Fill capability gap by adding long-range strike capability to MH-60S in ASuW	Complete missions using MH-60S	Operational/capability overlap between systems
Program Office PMA-299	1	Fill capability gap by adding long-range strike capability to MH-60S in ASuW	Provide naval aviators with tools to support ASuW	Operational/capability overlap between systems
Adaptive Force Package (AFP) Commander	1	Increase capability of an AFP by adding to the MH-60S Minimize impact to footprint of AFP to support additional MH-60S capability	Reduce number of blue force loses	Additional requirements for AFP
Operator	2	Operator training and manuals User friendly interface Safety interlocks to prevent inadvertent fire	Complete mission	Safety measures Added operational tasks
Maintainer	2	Maintainer training and manuals Safety interlocks to prevent inadvertent fire Manpower to support maintenance added capability	Maintain system (scheduled and unscheduled maintenance)	Safety measures Added maintenance tasks

Table 1. (Continued)

Stakeholder	Priority	Need(s)	Goal(s)	Concern(s)
Logistics	2	Repair, Spare item, and technical manual information Manpower to support new capability	Provide integrated logistics support	Increase in provisioned items Proper levels of repair defiled for system
Naval Air Systems Command (NAVAIR) Airworthiness Authority	3	Substantiation reports to support airworthiness approval Testing performed to support airworthiness approval	Verify system is safe for operating	Additional stress loads caused by integration of a long-range missile (LRM) Negative effects on aerodynamics Safety measures Critical safety items
Original Equipment Manufacturer (Sikorsky)	3	Integrate long-range strike capability onto MH-60S Testing performed to verify system requirements	Integrate system with minimal impact to airframe	Additional stress loads caused by integration Negative effects on aerodynamics Safety measures Critical safety items
Original Equipment Manufacturer (OEM) for Missile	3	Integrate onto-into MH-60S	Provide a safe and reliable missile to militaries to increase profits	Weapons interface Safety measures Missile load cases specific to MH-60S integration
Taxpayer	4	Maximize use of tax dollars	Procure cost effective system providing national security	Allocation of funding by Congress
Allied Forces	4	Fill capability gap by adding long-range strike capability to an H-60 variant	Defeat enemy forces	Integration challenges for H-60 variants

The USN has a primitive need to increase the operational effectiveness of the MH-60S for use in ASuW within DMO. The primitive need statement can be transformed into an effective need statement by assessing the top priorities identified in the stakeholder analysis. The effective need of the stakeholders is to determine if the addition of a LRM capability on the MH-60S increases the operational effectiveness of the AFP in ASuW within DMO. This effective need statement mirrors the goal of increasing the operational effectiveness as the primitive need statement; however, the effective need statement focuses the definition of the measures of effectiveness to be evaluated during the project.

B. FUNCTIONAL ANALYSIS

The scope of this project is defined as the evaluation of the addition of a LRM capability to the MH-60S to be used for BLOS ASuW missions in the DMO environment. A secondary goal of this project is to minimize the impacts of this new capability, and its required weapons changes, on other missions the MH-60S performs. To meet this goal, we completed an initial functional analysis, and from that analysis, determined that the project should focus on two specific areas of the functional hierarchy, Block 1.2.1: Receive Target Data from Link-16 and Block 1.2.2: Fire LRM. The broad context of the ASuW mission for the MH-60S is decomposed in Figure 2. We further decomposed Blocks 1.2.1 and 1.2.2 to identify the functional changes required for this mission profile to be successful.

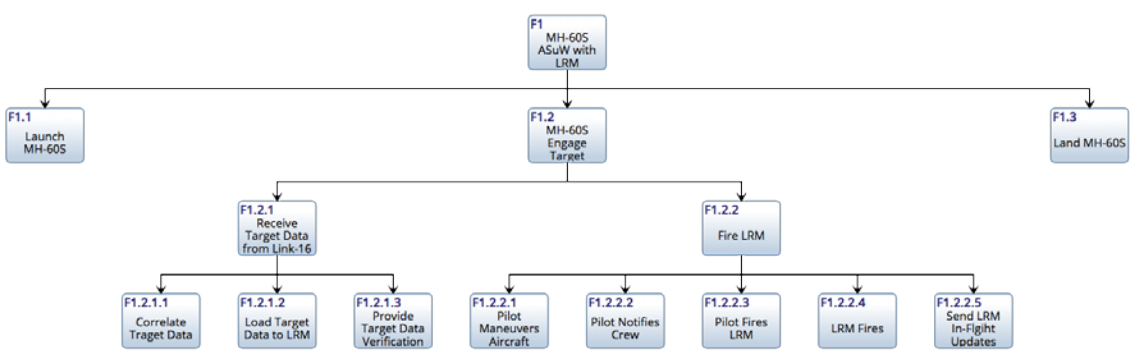

Figure 2. Functional Hierarchy of MH-60S ASuW with LRM Mission

The following list describes these functions with additional details provided for the new functions:

F1: MH-60S ASuW with LRM

F1.1: Launch MH-60S

F1.2: Engage Target

F1.2.1: Receive target data from data link: This function represents the process of the MH-60S receiving targeting data from Link-16. Due to the BLOS nature of this new mission and the lack of a long-range sensor suite on the MH-60S, an external source will transmit targeting data to be received via Link-16.

F1.2.1.1: Correlate target data: This function represents the process whereby the pilot can apply the targeting data received from Link-16 to the on-board mission computer and determine that it is valid. The pilot also uses this function to gain spatial awareness of the target location with respect to his or her own.

F1.2.1.2: Load target data to LRM: This function represents the process of relaying the target data from the mission computer to the LRM.

F1.2.1.3: Provide target data verification: This function represents the feedback mechanism whereby the LRM acknowledges that it has received the target handover message and is now ready to fire.

F1.2.2: Fire LRM

F1.2.2.1: Pilot maneuvers aircraft into launch position: This function describes the aircraft maneuvering required for the pilot effectively to engage the target. Data from function

F.1.2.1.1 enables the pilot to understand what heading is required for LRM launch.

F1.2.2.2: Pilot notifies crew of intent to fire LRM: This function describes standard weapons release protocol. Standing orders may require the addition of a broadcast radio call announcing weapons release.

F1.2.2.3: Pilot fires LRM: This function represents the action the pilot takes to initiate LRM launch. This action is the pilot interfacing with the aircraft.

F1.2.2.4: LRM fires: This function represents the actions required by the aircraft's weapons system to physically launch the missile. This action is the aircraft interfacing with the LRM.

F1.2.2.5: Send LRM in-flight updates (if applicable to LRM in use): This function represents the process of providing in-flight updates to the LRM if the selected weapon system supports this capability. Due to the BLOS nature of this new mission, target updates are expected to be received from an external source via Link-16, passed to the on-board mission computer, and then transmitted to the LRM. Alternatively, target updates could be passed directly from the external source to the LRM.

F1.3: Land MH-60S

Comparing the functional decomposition in Figure 2 to the current MH-60S ASuW mission confirms that the addition of the LRM does indeed affect the two areas of concern (F1.2.1 and F1.2.2). The two affected areas are further decomposed below in order to describe the degree of functional changes as compared to the current MH-60S ASuW mission.

The first area of impact is in the F1.2.1 Receive Target Data function. In the current MH-60S ASuW mission, the MH-60S is provided coarse targeting data from an MH-60R or other airborne intelligence, surveillance and reconnaissance (ISR) asset via Link-16 or other TCDL. The MH-60S pilot then utilizes the MTS/FLIR to locate, identify, and lase the target in preparation for a HELLFIRE missile strike or maneuver the aircraft into position for a fixed-forward firing weapon or crew served weapon (CSW) attack. The new LRM BLOS capability, by definition, will not allow the pilot to refine target data with the MTS/FLIR. This may require additional data to be provided via Link-16 from a platform capable of high altitude targeting to stratify the type and location of the enemy ship with sufficient resolution to provide the LRM with targeting data. This data will then be passed to the MH-60S mission computer in order for the pilot to effectively acknowledge the target and pass the information to the LRM. This new capability concludes with the LRM acknowledging the target data and returning a ready to launch status.

The second area of focus is in the F1.2.2 Fire LRM function that is similar to those used in the HELLFIRE missile ASuW mission, with the only changes being that the LRM will be launched instead of a HELLFIRE missile. Due to the long-range nature of the mission, the expected increased size and weight of the LRM may require adaptations to the current launch techniques for the HELLFIRE missile along with the quantity that it can employ. The LRM weapon system will likely have a weight range around one thousand pounds, so airframe response to missile launch will merit further investigation once a specific munition is determined. Additionally, the F1.2.2.5 Send LRM in-flight updates function was inserted as an option in case any of the available munitions support this capability. If the munition is capable of performing F1.2.2.5, this function would certainly require additional analysis to determine system and TCDL impacts. Based on these two potential changes, this function is annotated as impacted and will require further analysis when and if a new LRM weapon system is selected for the MH-60S.

Mission success is defined as the ability of the MH-60S equipped with the LRM to destroy the enemy target while remaining outside the weapons engagement zone (WEZ) of the enemy weapon systems while potentially remaining BLOS of the enemy. To answer the capstone project questions discussed in Chapter I, it is necessary to present both operational concerns and related measures of effectiveness (MOE) that assess the mission success of the MH-60S equipped with a LRM in a BLOS ASuW mission. Table 2 shows these operational concerns, which are based on higher-level objectives and decomposed into MOEs where analysis will be focused, for the MH-60S equipped with an LRM. These operational concerns quantitatively address how overall mission success is affected by the missile's physical and performance characteristics, suitability, and the effects of the required data link between the MH-60S and the AFP. The operational concerns and MOEs are decomposed further into measures of performance (MOPs) that help to quantitatively evaluate the impacts to overall mission success. For further discussions on these MOPs and how they are varied within the model, see Chapter III and Chapter IV.

The focus of this capstone project is on the added utility of the MH-60S within the ASuW mission. If the model does not show additional lethality with the MH-60S equipped with the LRM, there is no need to further research LRM data link, physical dimensions and suitability considerations. Therefore, the model for this project will focus on operational concerns in Table 2 that directly impacts the engage target function in Figure 2. Operational concern 3 is decomposed by MOEs a through d. The lethality of the MH-60S equipped with the LRM is measured by the reduction of threats that remain after the simulation, the reduction in the number of missiles fired upon the AFP, and the increase in enemy threats destroyed. While the data link from the AFP to the MH-60S and the LRM are key to the operational effectiveness of the MH-60S equipped with LRM, the model developed as part of this capstone project assumes the data link is always available. Based on the known weight of the HELLFIRE missile (107 pounds) (United States Army [USA] 2018), the MH-60S total weight of a loadout of eight HELLFIRE missiles (USN 2015) is approximately 856 pounds. The Naval Strike Missile (NSM) (Figure 3) is a currently available LRM weighing 897 pounds (Kongsberg Defence Systems 2017); therefore, it is assumed the MH-60S is capable of carrying two LRMs. Operational concern 4 focuses on the suitability of the LRM and the impacts to the suitability of the MH-60S. For example, Table 2 lists personnel and footprint as MOPs. If the added lethality of the LRM is demonstrated, consideration then shifts to the possibility of added personnel or additional facilities, such as storage, and whether they are worth the additional lethality the LRM provides. With these considerations in mind, operational concerns 1, 2 and 4 are outside the scope of this project but are still important for future evaluations of the LRM as part of the ASuW mission in the DMO environment.

Table 2. Measures of Effectiveness (Continued on Next Page)

Objectives	Trace to Functional Hierarchy	Lower Level Objectives	Operational Concerns and Measures of Effectiveness (MOEs)	Measures of Performance (MOPs)
Is the H-60S capable of finding and identifying the target of interest?	F1.2.1 Receive target data from Link-16	Ability to maintain communications with adaptive force package (AFP)	1) Does the MH-60S provide the necessary data to the LRM? a) Percentage of targets detected by MH-60S b) Average latency from forward observer sending coordinates to time of receipt c) Average time from target coordinates receipt to engagement	Time from request to engagement
		Ability of the payload to support mission		Payload imagery quality, zoom performance, etc.
Is the H-60 capable of fixing the target's location?	F1.2.1 Receive target data from Link-16	Ability to receive valid coordinates from a forward observer		Accuracy of coordinates
				Reliability of Link-16
Is the H-60S capable of tracking the target of interest?	F1.2 Engage Target	Ability to ingest track information		Accuracy of track information passed to missile
Is the H-60S capable of selecting an appropriate weapon for long-range engagements?	F1.2.2 Fire LRM	Ability to carry LRM	2) Is the MH-60S capable of carrying the LRM? (airworthiness)	Weight of missile
				Size of missile
				Compatibility with current missile launcher

Table 2 (Continued)

Objectives	Trace to Functional Hierarchy	Lower Level Objectives	Operational Concerns and Measures of Effectiveness (MOEs)	Measures of Performance (MOPs)
Is the H-60S capable of engaging a target at long range?	F1.2.2 Fire LRM	Ability to engage target greater than 50 nm	3) Does the MH-60S equipped with the LRM provide additional lethality? a) Percent reduction in threats to the AFP when the MH-60S is equipped with the LRM b) Percent reduction in C-802 engagements when the MH-60S is equipped with the LRM c) Percent increase in fast attack craft (FAC) destroyed when the MH-60S is equipped with the LRM d) Percent increase in fast inshore attack craft (FIAC) destroyed when the MH-60S is equipped with the LRM	Accuracy of missile
				Range of missile
				Impact velocity of missile
				Missile lethality
Is the LRM suitable for employment in United States Navy (USN) operations?	F1.1 Launch MH-60S F1.2 Engage target F1.3 Land MH-60S	Manpower	4) Is the LRM suitable for employment in USN operations?	Personnel needed to operate LRM
		Maintainability		Mean time to repair (MTTR)
				Maximum time to repair (MaxTTR)
				Tools needed
		Reliability		Mean time between failure (MTBF)
		Availability		Operational availability (A_o)

Table 2 (Continued)

Objectives	Trace to Functional Hierarchy	Lower Level Objectives	Operational Concerns and Measures of Effectiveness (MOEs)	Measures of Performance (MOPs)
Is the LRM suitable for employment in United States Navy (USN) operations?	F1.1 Launch MH-60S F1.2 Engage target F1.3 Land MH-60S	Training	4) Is the LRM suitable for employment in USN operations?	Training time
				Training personnel
				Training resources
		Operation in all environments		E^3, rain, ice, hot, cold, dust
		Support Equipment		Footprint

Figure 3. Naval Strike Missile. Source: Kongsberg Defence Systems (2017)

C. OPERATIONAL ANALYSIS

This report describes the concept of DMO and how the MH-60S would interact within this concept on the battlefield. Due to its limited deployment range, the MH-60S typically operates as part of a CSG or ARG. Future CONOPS may include the MH-60S deploying with guided missile cruiser and destroyers (CRUDES) or littoral combat ship (LCS) class of ships. The key differences between the CSG and ARG are not only the command ships, the nuclear aircraft carrier (CVN) or amphibious assault landing helicopter assault/dock (LHA/D), but also the strike package for the environment in which the MH-60S would be engaged in a strike. Typically, a CSG incorporates a USN Airwing that is composed of F/A-18 series aircraft, E-2 airborne early warning aircraft and a complement of MH-60R and S series helicopters. A typical ARG is mainly composed of United States Marine Corps AV-8B and is now being accompanied by the F-35B. Rotary-wing assets are typically MH-53E, AH-1Y & Z, UH-1 and MV-22. While the MH-60S is employed as a multi-mission helicopter, this CONOPS focuses on the ASuW mission and application of its weapons as an element within the AFP. Aircraft and ship force structure come from an already deployed CSG or ARG based on asset availability. Typically, these ships will travel independent of the CSG or ARG. The AFP composition is purely mission and asset availability dependent. Based on asset availability and strike group composition, the AFP will consist of multiple guided missile destroyers (DDGs), guided missile cruisers (CGs), LCS and potentially a multi-spot amphibious ship. With the addition of an amphibious ship, the capability would be added to have organic fixed-wing support. Due to the commander's intent of such an AFP, there may not be CSG-based fixed-wing assets available due to their range from the CSG.

As with DL, the key point of a DMO environment is that the enemy would be kept as far away as possible in order to keep friendly forces outside the WEZ of the enemy's weaponry. As Figure 4 shows, the command ship is able to communicate BLOS via satellite communications (SATCOM) and TCDL with other friendly forces and relay information and the tactical picture for up-to-date situational awareness. The AFP's distance from the CSG or ARG will drive whether a strike package from the CSG / ARG is available. In a situation where a strike package is unavailable, the MH-60S will deploy with an LRM loadout. As stated previously, this effort has assumed the MH-60S is capable of carrying two LRMs as a full loadout, and other MH-60S assets retain the baseline loadout and capabilities of an AFP. As such, current capability MH-60S aircraft will be airborne with a conventional loadout of HELLFIRE missiles and fixed forward firing weapons. In keeping with the dynamic targeting process, a friendly surface combatant or airborne MH-60R identifies a target and passes it through the TCDL to all surface and airborne assets and the cognizant combatant commander then makes a determination on the threat. Based on the posturing of the enemy, the combatant commander would give a target order, which passes through traditional communications or through the TCDL. The MH-60S remains outside of the WEZ of the enemy's defensive weapons for the entirety of the engagement. Since the MH-60S does not have organic target tracking, the MH-60S passes the BLOS target information to the LRM loaded on the rail. Even though the MH-60S cannot track or see the target, the LRM is provided a handover to allow it to acquire the target in flight, keeping the MH-60S clear of any enemy fire. With the MH-60S, MH-60R, and fixed-wing assets, if available, the AFP can successfully engage enemy combatants before they have the ability to fire.

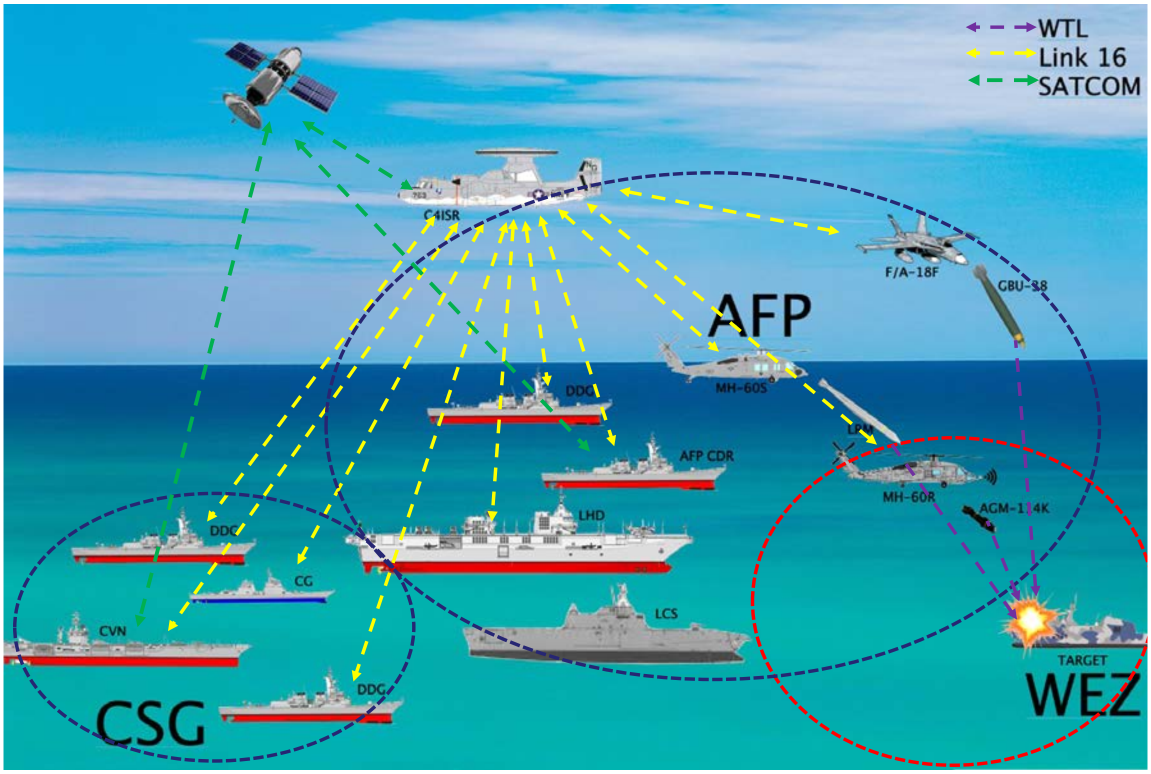

Figure 4. AFP Operational View

The current capability gap of the AFP is the lack of a rotary-wing launched, long-range standoff weapon. As the USN modifies its current tactics to better align with engaging A2/AD systems, it must work to increase capabilities in engaging longer-range targets. The first step is moving away from the standard CSG / ARG configuration, which is based on a large command ship with additional surface assets and focuses on layered defense outward from the command ship. DMO, in the configuration described above, helps increase naval reach against enemy combatants using different configurations of ships to best make up an AFP. However, there are no current rotary-wing based long-range weapons to help defend the AFP. As enemy weapons can reach further out, including anti-ship cruise missiles and air-launched cruise missiles, the AFPs must be able to engage targets from larger standoff ranges.

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III. MODELING AND SIMULATION

A. CONSTRAINTS, LIMITATIONS, AND ASSUMPTIONS

A discrete event simulation model was created within Imagine That Incorporated's ExtendSim software package using the functional architecture, AFP configuration, aircraft assumptions, and aircraft limitations defined in Chapters I and II. The model simulates the standard ASuW scenario with an integrated MH-60S BLOS capability shown in Figure 7. The model is limited on the asset's ability to maneuver to avoid threats and is limited to a two-dimensional environment. It conforms to current personnel and logistics limitations for the MH-60S and presents minimal impacts to current operational tactics and other MH-60S missions. It is assumed that all AFPs will contain an MH-60S with a long-range capability and that variances in ship types will not vary the results of the analysis. Assumptions were made for the enemy's capabilities to attack and defend against the AFP and for the AFP's capabilities to attack the enemy and defend itself as described in Chapter II. The assumptions for the enemy forces are shown in Table 3 and the assumptions for the AFP are shown in Table 4. It is important to note the assumed capability values are estimations based on the team's professional experience and are not actual documented values to avoid compromising any classified data. Users of the model with a valid need-to-know and appropriate clearance can access the ExtendSim data files and input actual values to obtain a more accurate representation.

Table 3. Enemy Capability Assumptions

	Quantity	Deployment Range	Speed	Engagement Range	Probability of Hitting an AFP Component	Probability of Destroying an AFP Component
FAC	2 to 10	120km	20m/s	120km	98%	70%
FIAC	5 to 20	12km	30m/s	2km	80%	50%

Table 4. AFP Capability Assumptions

Model AFP Configuration	
Guided Missile Destroyers	2
Guided Missile Cruiser	1
Littoral Combat Ship	1
Amphibious Ship	1
MH-60S	1-4
MH-60R	1
Fixed Wing Asset for data link BLOS Data Relay	1
FAC[3] Detection Range	200km
FIAC[4] Detection Range	10km
Probability of Detecting a FAC/FIAC	80%
Available MH-60 Load Out	
MH-60S	Two LRMs
	Four HELLFIRE missiles and 19 2.75" short-range rockets
	Trade Space Analysis with either LRMs, HELLFIRE missiles, 2.75" short-range rockets, or a combination
MH-60R	One for target data delivery
LRM	
Quantity Available per Platform	2
Range	5km-185km
Probability of Hitting a FAC/FIAC	90%
Probability of Single Shot Kill	1
Velocity	100m/s
HELLFIRE Missile	
Quantity Available per Platform	4
Range	1.5km-8km
Probability of Hitting a FAC/FIAC	80%
Probability of Single Shot Kill	50%
Velocity	450m/s
2.75" Short-Range Rockets	
Quantity Available per Platform	19
Range	1.5km-5km
Probability of Hitting a FAC/FIAC	70%
Probability of Single Shot Kill	25%
Velocity	1000m/s

The fast attack craft (FAC) threat was modeled after the Iranian Navy and Islamic Revolutionary Guard Corps Navy's Thondar class of missile boat as seen in Figure 5. The Thondar, also known as the Houdong class by the Chinese Navy, is 38 meters in length and can travel at speeds up to 35 knots. The FAC represented in the model is armed with four C-802 anti-ship cruise missiles (ASCM), a 30mm naval gun, and a 23mm naval gun (Global Security 2011). During a Senate Governmental Affairs Committee meeting on April 11, 1997, then Deputy Assistant Secretary of State Robert Einhorn stated "that the C-802 cruise missiles pose new, direct threats to deployed United States forces" (Global Security 2011, para. 4).

Figure 5. Iranian Navy Thondar Source: Military Edge (n.d.).

The fast inshore attack craft (FIAC) threat was modeled after the Islamic Revolutionary Guard Corps Navy's Bladerunner 51 as seen in Figure 6. The Bladerunner 51 is an armed version of a 15.5 meters long British produced speedboat, and has a top speed of 65 knots (Jamieson 2010). When armed, the Bladerunner 51 is typically loaded with small arms, rocket propelled grenades, rockets, man-portable air-defense systems, and other small munitions.

Figure 6. Islamic Revolutionary Guard Corps Navy Bladerunner 51. Source: The Maritime Executive (2016).

For the purposes of this project, it was assumed that the FAC and/or FIAC would be deployed from a distance of 120km and 12km respectively. The detection range of the AFP is 200km, so the FAC and FIAC threats are detected as soon as they are deployed. Once the FAC and FIAC are detected, the MH-60S receives the target location data via Link-16 and proceeds to engage the enemy with its LRM. If the MH-60S is successful it disengages, otherwise it may re-engage if the enemy is still within the LRM assumed range of 5km-185km. If the MH-60S is not successful, either the AFP's mid-range HELLFIRE missile (1.5km-8km) or the short range 2.75 inch rocket (1.5km-5km), is employed depending on the current enemy location. A pictorial representation of the ASuW scenario to be modeled for this effort is shown in Figure 7.

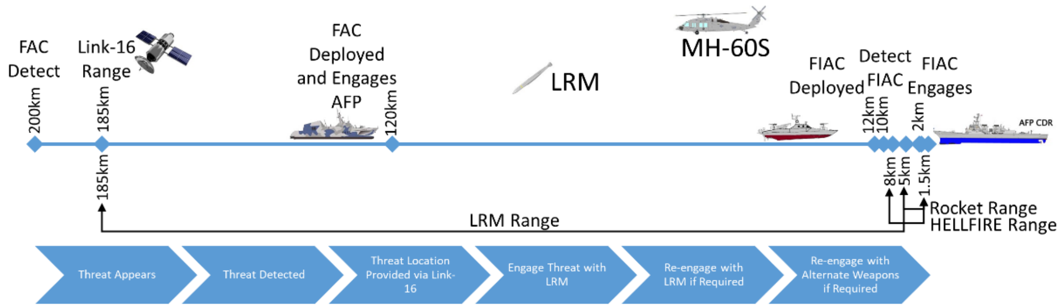

Figure 7. ASuW Scenario for ExtendSim Modeling. Adapted from Davis (2017).

B. APPROACH

For this project, the DMO architecture presented in the NPS December 2017 thesis entitled “Development of Systems Architecture to Investigate the Impact of Integrated Air and Missile Defense in a Distributed Lethality Environment” by Justin K. Davis (Davis 2017), was adopted as the current CONOPS for DMO and modified to reflect a CONOPS for DMO that incorporates the MH-60S with a BLOS ASuW capability. A discrete event simulation was used to model an AFP within DMO, to analyze the benefits of the MH-60S long-range, BLOS capability, and to determine the weapons system capabilities required to maximize the benefits to the USN. With weapon system capability requirements optimized, available weapon systems were analyzed to determine the recommended long-range solution. If no long-range solution is available, recommendations were made for future research. A sensitivity analysis of Link-16 availability and operational effectiveness should be conducted to determine if existing targeting sensors support the BLOS capability; however, for the purposes of modeling and simulation it is assumed that Link-16 will always be available for targeting.

In order to perform the simulation, an ExtendSim model was created to simulate the following ASuW scenario. A potential target is identified by a MH-60R or other airborne asset, and target location data is transmitted to the combatant commander via Link-16. Upon determination to fire, the target data is provided to the MH-60S outside of the target’s WEZ via Link-16. If the target is a FAC, the MH-60S then launches one of the two LRMs available. If the target is a FIAC, a probability estimate is used to randomly determine if the MH-60S will fire one LRM or leave the FIAC for shorter-range weapons. The target is then assessed by an MH-60R or other airborne asset to determine the success of the launch. If the initial engagement is successful in neutralizing the target, the MH-60S disengages; otherwise, the combatant commander either tasks the MH-60S to reengage the target with another LRM (if available), HELLFIRE missile, or short-range rocket, or transfers the mission to another AFP component. Once the target enters the AFP's WEZ, the AFP's short-range weapons engage the target until either the target is destroyed or the enemy is successful in hitting an AFP component. The functional flow block diagram (FFBD) for the scenario described is shown in Figure 8.

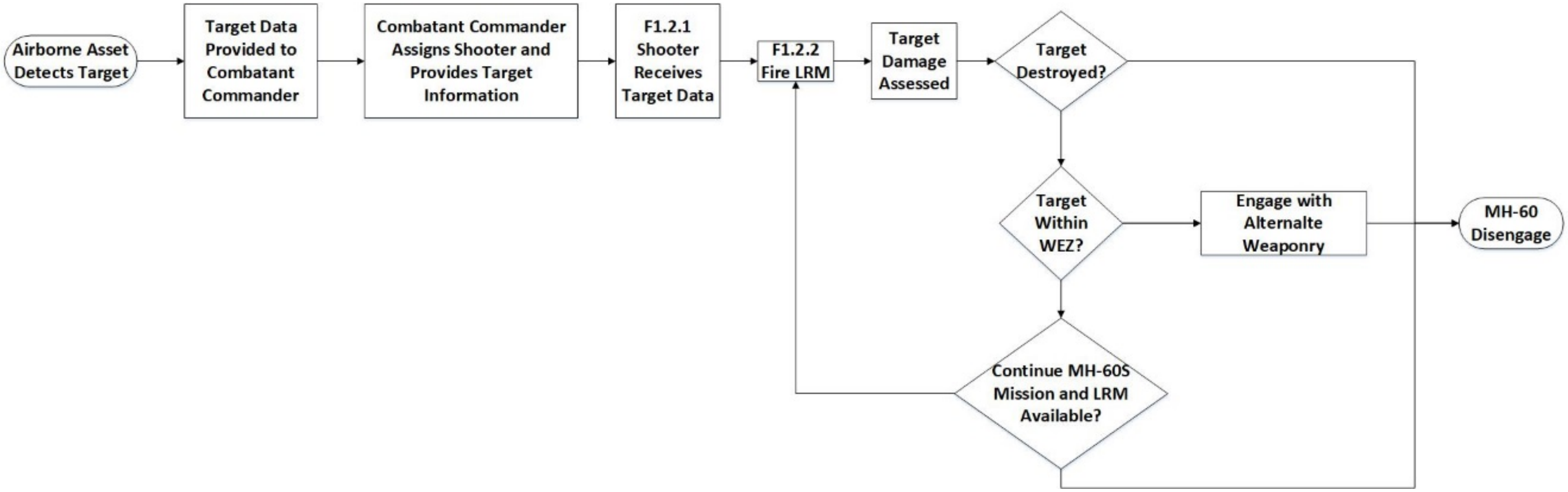

Figure 8. ASuW Scenario Functional Flow Block Diagram

The intent of the model is to provide insight to the team to answer the project questions proposed in Chapter I. The first task is to determine if the MH-60S can be used in greater capacity in the DMO for ASuW missions, and the second task is to examine the trade space of long-range ASuW weapons that can be added to the MH-60S to affect the DMO environment. To facilitate answering these questions, the model was partitioned into four major tasks, as shown in Figure 9.

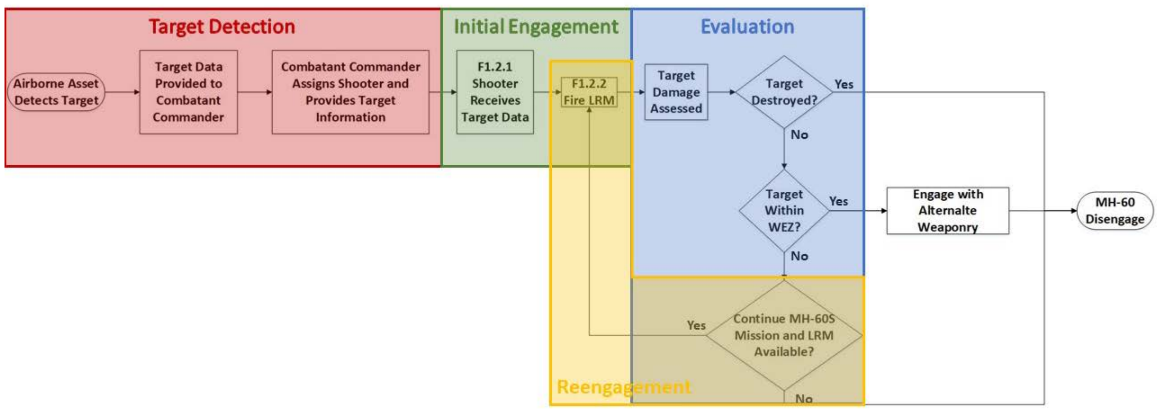

Figure 9. Major Tasks of FFBD

1. Target Detection

Target detection begins when enemy threats, FAC and/or FIAC, are initiated. The specific parameters, such as quantity, range, and speed of the FACs and FIACs are assigned to each threat by a database. The threat databases can be changed to evaluate different threats as needed. The model then determines if the threat is within the detection range of the AFP's ISR asset. If the threat is not within the detection range of the ISR asset, the threat continues through a range assessment loop until the threat is within range. Once within the detection range, the threat is put into a queue with any existing threats that have not yet been detected. The ISR asset detects 80% of the FAC and FIAC threats as soon as they are deployed. After detection, the threat moves to a tracking queue with any existing threats that have not moved onto the engagement task. The threat range is then calculated and the threat either moves onto the engagement task or is considered a missed threat. Threats missed by detection are recorded in an output data file and are considered as threats to the AFP.

2. Initial Engagement

The initial engagement of threats begins by calculating the age of the threats to determine if they are within range of the weapon systems of the MH-60S. The parameters of the LRMs, HELLFIRE missiles, and short-range rockets are assigned to each weapon system by a database. The model uses the parameters of the threats to determine if the AFP is within the WEZ of the threat and is fired upon by enemy ships. A count of the number of times the AFP is fired upon is recorded in an output data file. Next, the model determines the number of LRMs available to engage the threat. If the threat is a FAC and an LRM is available, the threat is engaged using the LRM. If the threat is a FIAC and an LRM is available, a probability estimate of 70% is used to randomly determine if the MH-60S will fire the LRM or leave the FIAC for shorter-range weapons. This probability factor is inserted to add an element of operational realism to the simulation for events such as the non-LRM aircraft already being tasked or on the opposite side of the AFP from the threat. Those threats are then sent to the evaluation task. Threats that survive the LRM engagement, those outside the LRM window, and threats that arrive when no LRMs are available to engage, are put into a queue to be sent to the re-engagement task.

3. Evaluation

Evaluation begins when the first enemy threat is engaged. The model uses a 90% probability of hit parameter for the LRM, along with a constant probability of single shot kill (PSSK) of one to determine if the threat is destroyed or survives. Similarly, for any threat engaged by the HELLFIRE missiles or short-range rockets, the model determines if the threat is destroyed or survives using the probability of hit parameter and PSSK as assigned to each weapon system in Table 4. Threats that are destroyed are recorded in an output data file. Threats that survive move on to the re-engagement task.

4. Re-engagement

Re-engagement occurs for all threats within the model that are not destroyed. The model uses the parameters of the threats to determine if the AFP is within the WEZ of the threat and is fired upon. A count of the number of times the AFP is fired upon is recorded in an output data file. The ages of threats that survive a previous engagement or have not yet been engaged due to range or lack of LRM inventory are used to determine the range of the threat. Based on the range of the threat, the model sends the threats to be engaged by the LRM (if available) or to a queue until they are within the engagement ranges of the HELLFIRE missiles or short-range rockets. Threats that are engaged by the LRM, as in the initial engagement task, are then sent to the evaluation task. The shorter-range missile engagement of threats is similar to that of the initial engagement task utilizing the LRM. After the 70% probabilistic estimate is used to randomly select the shorter-range weapons, the threat's age is determined to evaluate if the threat is within the HELLFIRE missile range. If so, it is routed to another probabilistic selection between the HELLFIRE missile and short-range rockets. If not, it is taken through the same type of range assessment loop as the LRM engagement and held in a queue until within range. Next, the model determines the number of HELLFIRE missiles available to engage the threat. If a HELLFIRE missile is available, the threat is engaged using the HELLFIRE missile. Those threats are then sent to the evaluation task. Threats that survive the HELLFIRE missile engagement, those outside the HELLFIRE missile engagement window, threats that arrive when no HELLFIRE missiles are available to engage, and the threats routed randomly to the short-range rockets are sent to a queue to be engaged by the short-range rockets. As with the LRMs and HELLFIRE missiles, the engagement using the short-range rockets is modeled using the same logic. Threats engaged by the short-range rockets are then sent to the evaluation task. Threats not destroyed by the short-range rockets are recorded in an output data file as a potential threat to the AFP.

5. Design of Experiments

In order to clearly understand the impact of the LRM in the ASuW mission, a screening DOE was created in Minitab 17 software using the factors identified as having the greatest impact on operational concern 3 and corresponding MOEs: the number of FACs and FIACs in the operational scenario, the number of MH-60S in the AFP, the number of LRMs each MH-60S is equipped with, the LRM engagement range, the LRM probability of destroying an enemy craft, the LRM velocity, and the probability of the AFP detecting an enemy craft. With the exception of the probability of the AFP detecting an enemy craft, these factors and their minimum and maximum values were used to create a full factorial screening DOE and input matrix for use in the ExtendSim model. The probability of the AFP detecting an enemy craft is considered outside the scope of this project and was held constant at 80% based on publically available research of detection systems. The data required to address the project questions was collected from the model's output database and analyzed using Minitab's factorial analysis function. This allowed the team to reduce the screening DOE matrix to include only statistically significant factors. An 8-factor, space-filling DOE input matrix was then created and input into the model, and the resulting outputs from the simulation were extracted from the output table and loaded into JMP 13 statistical software for a detailed analysis of the effects of adding the MH-60S equipped with LRM on the ASuW mission.

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IV. RESULTS

A. RESULTS OF THE DESIGN OF EXPERIMENTS

In any DOE, it is important to ensure there is minimal correlation between columns of the input matrix. Therefore, a screening DOE was created in Minitab 17 software using the factors from the model shown in Table 5. This 10-factor, 2-level (minimum and maximum), full factorial screening DOE was replicated 30 times and used to generate a matrix for use in the ExtendSim model. The values in this 30,720-line matrix were inserted into the appropriate database tables as inputs in the ExtendSim model. All other factors in the model were held constant at their maximum values since they were determined to be outside the scope of the project.

Table 5. Factors Used in the Screening DOE

Factor	Description	Minimum Value	Maximum Value
NUM FAC	Number of Fast Attack Craft	2	10
NUM FIAC	Number of Fast Inshore Attack Craft	5	20
NUM H60 LRM Trucks	Number of MH-60S's with LRMs	0	3
NUM LRM	Number of LRM per MH-60S	1	2
LRM MAX Range	LRM Maximum Range	150km	200km
LRM MIN Range	LRM Minimum Range	2km	10km
LRM Phit	Probability of LRM hitting a FAC/FIAC	70%	90%
LRM Velocity	LRM Velocity	60m/s	120m/s
Pdetect	Probability of Detecting a FAC/FIAC	60%	100%
MIXED LRM	Mixed LRM and HF/Rocket Loadout	1	2

The model completed all simulation runs and the data required to address the project questions were collected from model's output database and inserted into Minitab. For the screening experiment, the relevant MOEs are "Threat to AFP" and "C-802 Engagements." The "Threat to the AFP" MOE is the total number of FACs and FIACs that remain at the end of the simulation and pose a direct threat to the AFP. The "C-802 Engagements" MOE is the total number of ASCM fired by all the FACs during the simulation.

Regression analysis was performed on these two MOE, using the 10 factors from Table 5 to estimate the effects of main factors, as well as their interactions. The resultant p-value for each main and interaction effect was compared to our desired confidence level of 90% or an alpha of 0.10. The main effects and interactions which had p-values less than alpha are shown in Table 6 and Table 7. While the probability of detecting (Pdetect) a FAC or FIAC is a significant factor in the overall success of the LRM, it is a factor that is controlled by a support platform in the ASuW mission and is not attributable to the LRM itself. Therefore, it was considered outside the scope of this project and was not used in the final DOE. Its value was held constant at 80% based on publically available research of detection systems. Additionally, it was determined that MIXED LRM was a flag to denote the number of LRM per MH-60S (NUM LRM) and was not used in the final DOE. The remaining factors, shown in Table 8, were considered significant to the LRM simulation and were used in the creation of the final DOE input matrix.

With the screening DOE matrix reduced to include only statistically significant factors, an 8-factor, space-filling DOE input matrix was created using the "512 point NOB" Excel spreadsheet (Vieira 2012). A correlation matrix was developed for the refined input matrix that showed a maximum correlation of 0.024 thus confirming minimal correlation existed for this design matrix and is acceptable for this project. To reduce the random error and normalize the data in the model, the refined input matrix was then replicated 30 times and inserted into the appropriate input tables in the model database. Finally, 15,360 simulations were run, and the resulting values that will support operational concern 3 are shown in Table 9. The resulting outputs from the simulation were extracted from the model and loaded into JMP 13 statistical software for a detailed analysis of the effects of adding the MH-60S equipped with an LRM on the ASuW mission.

Table 6. Threat to AFP Significant Main Effects and Interactions

Main Effect	***p*-value**
NUM FAC	0.000
NUM FIAC	0.000
NUM H60 LRM Trucks	0.000
NUM LRM	0.000
LRM MIN Range	0.000
LRM Phit	0.000
Interaction	***p*-value**
NUM FAC*NUM FIAC	0.001
NUM FAC*NUM H60 LRM Trucks	0.000
NUM FAC*NUM LRM	0.000
NUM FAC*LRM MIN Range	0.000
NUM FAC*LRM Phit	0.005
NUM FIAC*NUM H60 LRM Trucks	0.000
NUM H60 LRM Trucks*NUM LRM	0.000
NUM FIAC*LRM MIN Range	0.002
NUM FIAC*LRM Velocity	0.045
NUM H60 LRM Trucks*NUM LRM	0.000
NUM H60 LRM Trucks*LRM Min Range	0.000
NUM H60 LRM Trucks*LRM Phit	0.000
NUM LRM*LRM MAX Range	0.029
LRM MIN Range*LRM Phit	0.063
LRM MIN Range*LRM Velocity	0.046
LRM MIN Range*MIXED LRM	0.034
LRM Phit*Pdetect	0.059

Table 7. C-802 Engagements Significant Main Effects and Interactions

Main Effect	***p*-value**
NUM FAC	0.000
NUM H60 LRM Trucks	0.000
NUM LRM	0.007
LRM MIN Range	0.000
LRM Phit	0.014
Interaction	***p*-value**
NUM FAC*NUM FIAC	0.098
NUM FAC*NUM H60 LRM Trucks	0.000
NUM FAC*NUM LRM	0.003
NUM FIAC*NUM H60 LRM Trucks	0.092
NUM FIAC*LRM Velocity	0.063
NUM H60 LRM Trucks*NUM LRM	0.034
NUM H60 LRM Trucks*LRM MIN Range	0.002
NUM H60 LRM Trucks*LRM Phit	0.094
LRM MIN Range*LRM Velocity	0.078
LRM Phit*Pdetect	0.035

Table 8. Factors Used in the Final DOE

Factor	**Number of Levels**	**Values**
NUM FAC	4	2, 5, 7, 10
NUM FIAC	5	5, 9, 13,16, 20
NUM H60 LRM Trucks	4	0, 1, 2, 3
NUM LRM	2	1 or 2
LRM MAX Range (km)	11	150, 155, 160, 165, 170, 175, 180, 185, 190, 195, 200
LRM MIN Range (km)	9	2, 3, 4, 5, 6, 7, 8, 9, 10
LRM Phit (%)	5	70, 75, 80, 85, 90
LRM Velocity (m/s)	7	60, 70, 80, 90, 100, 110, 120

Table 9. Outputs for Analysis Impacting Operational Concern 3

Output	Description
H-60 LRM Kill	Total enemies (FAC + FIAC) destroyed by LRM
H-60 HF Kill	Total enemies (FAC + FIAC) destroyed by HELLFIRE
H-60 Rocket Kill	Total enemies (FAC + FIAC) destroyed by rockets
Threat to AFP	Total enemies (FAC + FIAC) destroyed
Missed	Total enemies (FAC + FIAC) not destroyed
Total Enemy Shots	Total enemies (FAC + FIAC) shots taken at the AFP
LRM Killed FACs	Total FACs destroyed by LRM
LRM Killed FIACs	Total FIACs destroyed by LRM
HF Killed FACs	Total FACs destroyed by HELLFIRE
HF Killed FIACs	Total FIACs destroyed by HELLFIRE
Rockets Killed FACs	Total FACs destroyed by rockets
Rockets Killed FIACs	Total FIACs destroyed by rockets
Time of Last Kill	Simulation time when last enemy destroyed
FACs Remaining	Total FACs remaining at the end of simulation
FIACs Remaining	Total FIACs remaining at the end of simulation
C-802 FAC Engagements	Total number of anti-ship missiles fired by FACs
FAC Gun Shots Taken against AFP	Total number of weapons engagements by FACs
FIAC Small Arms Fires taken against AFP	Total number of weapons engagements by FIACs

B. RESULTS OF MODELING AND SIMULATION

In order to analyze the capability impact of the LRM integrated on the MH-60S, a baseline simulation model was run with a loadout of only HELLFIRE missiles and 2.75" short-range rockets. Therefore, the total number of LRMs in the AFP was set equal to zero and all other factors were varied per the DOE defined in Chapter III. Four outputs are significant to analyze in order to gain insight into the project questions for this project. They include the two responses defined in Chapter III, "Threats to the AFP" and "C-802 Engagements," as well as "FACs Destroyed" and "FIACs Destroyed," with "FACs Destroyed" being the total number of FACs destroyed by the AFP and "FIACs Destroyed" being the total number of FIACs destroyed by the AFP. Since the number of FACs and FIACs are varied input factors, the average number of threats to the AFP, C-802 engagements, FACs destroyed, and FIACs destroyed are better represented as percentages of the total values. Table 10 shows the mean percentage and standard deviation (Std Dev) of the response results for the replications of the baseline model. It is important to note that, on average, 100.0% of the FIACs were destroyed with a standard deviation of 0.0% without the use of LRMs. The equations used to calculate the percentages for each of the responses are shown in Equations 1–4.

$$(1) \qquad Threat\ to\ the\ AFP_{percent\ of\ the\ total} = \frac{Threat\ to\ the\ AFP}{FACs\ Deployed + FIACs\ Deployed}$$

$$(2) \qquad C-802\ Engagements_{percent\ of\ the\ total} = \frac{C-802\ Engagements}{(FACs\ Deployed)(4)}$$

$$(3) \qquad FACs\ Destroyed_{percent\ of\ the\ total} = \frac{FACs\ Destroyed}{FACs\ Deployed}$$

$$(4) \qquad FIACs\ Destroyed_{percent\ of\ the\ total} = \frac{FIACs\ Destroyed}{FIACs\ Deployed}$$

Table 10. Baseline Results

	Threat to the AFP	**C-802 Engagements**	**Percentage of FACs Destroyed**	**Percentage of FIACs Destroyed**
Mean (%)	31.1%	65.1%	8.7%	100.0%
Std Dev (%)	15.8%	9.6%	18.8%	0.0%

1. Stepwise Regression Analysis

Table 8 in Chapter III lists the eight input factors analyzed in order to determine if there are any regression issues with the simulation results. The number of MH-60S aircraft in the AFP is driven by the total number of LRMs required, so the factor of the number of MH-60S aircraft will be ignored until the number of LRMs is determined. As previously stated, 100% of FIAC threats were destroyed without the use of LRMs, so this response result is not included in the regression analysis. In order to analyze the impact of the remaining seven DOE factors, a stepwise regression model was developed for the FACs destroyed, threat to the AFP, and C-802 engagements. The R^2 value, also known as the coefficient of determination, for each of the responses is 0.45, 0.88, and 0.93 respectively. The coefficient of determination is a statistical measure used to define the "proportion of the total variability accounted for by the regression line" (Hayter 2013, 581).

The stepwise regression model determined *p*-values for each of the input factors. A *p*-value is often referred to as the "observed level of significance" (Hayter 2013, 350). Since the *p*-values for most of the factors were extremely small, the LogWorth for each factor was calculated using Equation 5 to better show the scale of effectiveness and differentiate between the factors. All values are depicted in Figure 10 to show the scale of the relationship of significant factors. It is evident that the number of enemy FACs is by far the most impactful of any of the factors. Any factor with a LogWorth equal to or less than 1, or a *p*-value equal to or greater than 0.1, is not considered significant.

$$(5) \qquad LogWorth = -\log 10\,(p - value)$$

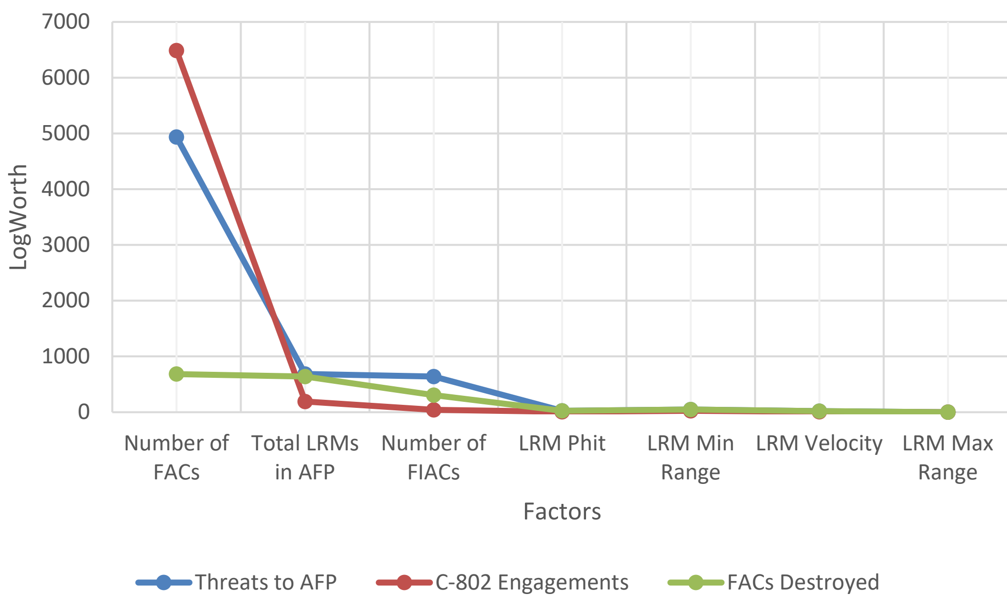

Figure 10. Scale of the Relationship of Significant Factors

The LRM maximum range factor is not significant due to a low LogWorth. LRM Phit, minimum range, and velocity are low but not statistically insignificant; therefore, these factors were analyzed separately using another stepwise regression model for only the LRM capability factors. The R^2 values are 0.00, 0.00, and 0.03 for C-802 engagements, threat to the AFP, and total FACs destroyed respectively; therefore, the capabilities of the LRM are not significant factors in this model for the number of C-802 engagements, threats to the AFP, or the total FACs destroyed by the AFP. The LRM capabilities are deemed insignificant due to their negligible impact to model performance. The maximum and minimum ranges affected only the engagement envelope. Since the LRM can engage up to the engagement range of the FAC in the DOE, modifying maximum range was not applicable. The minimum engagement range was not an issue due to the LRMs being expended long before the target entered the minimum engagement range. Varying LRM Phit did not affect the number of FACs or FIACs destroyed in the model. Also, LRM velocity only affected engagement timelines, but not the amount of LRMs fired. With the LRM capability factors determined to be insignificant in this model, another stepwise regression model was developed for the remaining factors: number of FACs, total LRMs in the AFP, and number of FIACs. The R^2 values are 0.92, 0.87, and 0.43 for C-802 engagements, threat to the AFP, and total FACs destroyed respectively. This shows that our three significant input factors, number of FACs, number of FIACs, and total number of LRMs in the AFP, have a high correlation to the regression analysis. All three of these factors must be included as inputs to retain this high correlation.

2. Detailed Analysis of Significant Factors

Three input factors are significant: number of FACs, total LRMs in the AFP, and number of FIACs. To examine these factors in greater detail, the simulation model completed 15,360 total simulation runs varying all of the input factors per the DOE defined in Chapter III. As the total number of LRMs in the AFP increases, the mean percentage of threats to the AFP and C-802 engagements decreases while the percentage of FACs destroyed increases showing a positive effect to the operational effectiveness of the MH-60S. Of particular interest, the percentage of FIACs destroyed does not significantly increase or decrease with the addition of the LRM. This is most likely due to the high PSSK of 1.0 against FIACs, which was based on their small size and fiberglass hull construction. This is a realistic assumption due to the class of the missile, size of warhead, and size of rocket motor. With such a high PSSK, the FIACs are destroyed with HELLFIRE missiles and 2.75” rockets, so there is no expected effect from LRM use. Table 11 shows the percent total value for each of the four responses.

Table 11. Percent Total Values for Responses Affected by the Number of LRMs

Total LRMs in AFP	Percentage Threat to the AFP		Percentage of C-802 Engagements		Percentage of FACs Destroyed		Percentage of FIACs Destroyed	
	Mean	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
0	31.1%	15.8%	65.1%	9.6%	8.7%	18.8%	100.0%	0.0%
1	25.7%	14.2%	62.1%	9.9%	21.4%	25.7%	100.0%	0.0%
2	23.6%	14.5%	60.3%	10.8%	27.9%	28.9%	100.0%	0.0%
3	21.2%	14.7%	59.1%	10.7%	35.8%	30.8%	100.0%	0.0%
4	19.2%	12.7%	57.0%	10.0%	42.5%	30.4%	100.0%	0.0%
6	19.3%	12.5%	56.8%	10.2%	42.4%	29.4%	100.0%	0.0%

On average with zero LRMs in the AFP, 31.1% of threats are not being destroyed by the MH-60S with HELLFIRE missiles and rockets only, allowing the enemy to utilize 65.1% of its available C-802 missiles against the AFP, and the percentage of FACs destroyed by the AFP is only 8.7%. Increasing the total number of LRMs to four will decrease the threats to the AFP and C-802 engagements to 19.2% and 57.0% respectively and will increase the percentage of FACs destroyed to 42.5%. Increasing the total number of LRMs from four to six does not show an increase in average effectiveness. Figure 11 shows that the increase in effectiveness of adding LRMs is relatively constant from zero to four LRMs; however, the impact to effectiveness of bringing the total number of LRMs up to six is negligible. This negligible impact is most likely due to two factors. First, as threat numbers increase, LRMs are being used to defend against the larger increases in FIAC threats rather than the FACs threats. Second, the LRMs are all expended prior to any threat reaching LRM minimum engagement range.

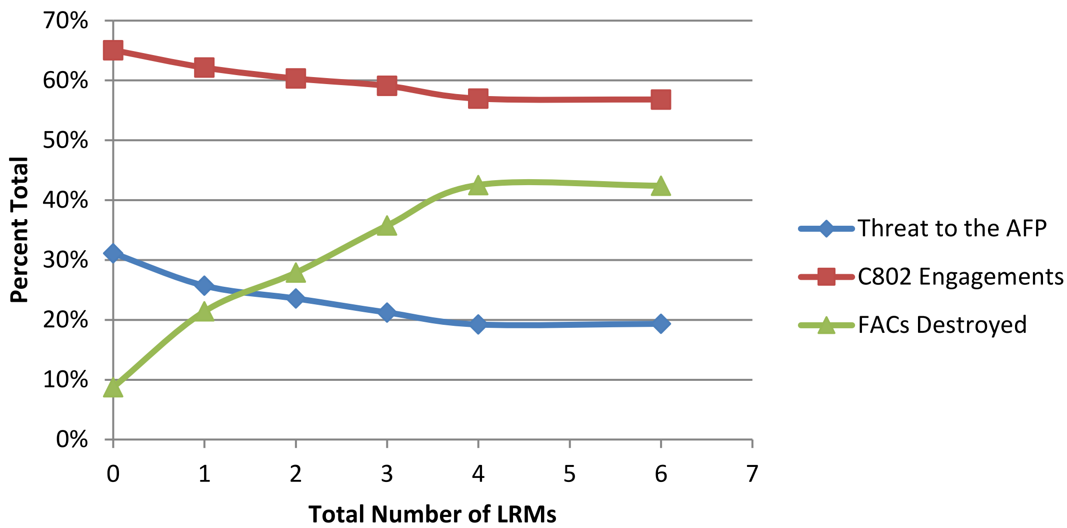

Figure 11. Percent Totals versus Total Number of LRMs

The percentages of FIACs destroyed in Table 11 are consistently 100.0% with a standard deviation of 0.0% for all scenarios. This indicates the baseline MH-60S loadout of HELLFIRE missiles and 2.75” short-range rockets is sufficient for this threat; however, Figure 12 shows that some LRMs are being used to destroy FIACs in the simulation model. The number of LRMs used to destroy FIACs is dependent upon the number of available LRMs and the number of threats deployed by the enemy. The number of FIACs destroyed by LRM increases when the number of FACs is low and the number of total LRMs increases as there are simply more FIACs to shoot at relative to the number of FACs; the total number of FIACs destroyed by LRM ranges from 0.4 to 3.8 over all scenarios. Since the baseline MH-60S loadout is sufficient to destroy 100% of FIACs in all scenarios and the number of LRMs will be limited, all LRMs should be reserved for FACs only.

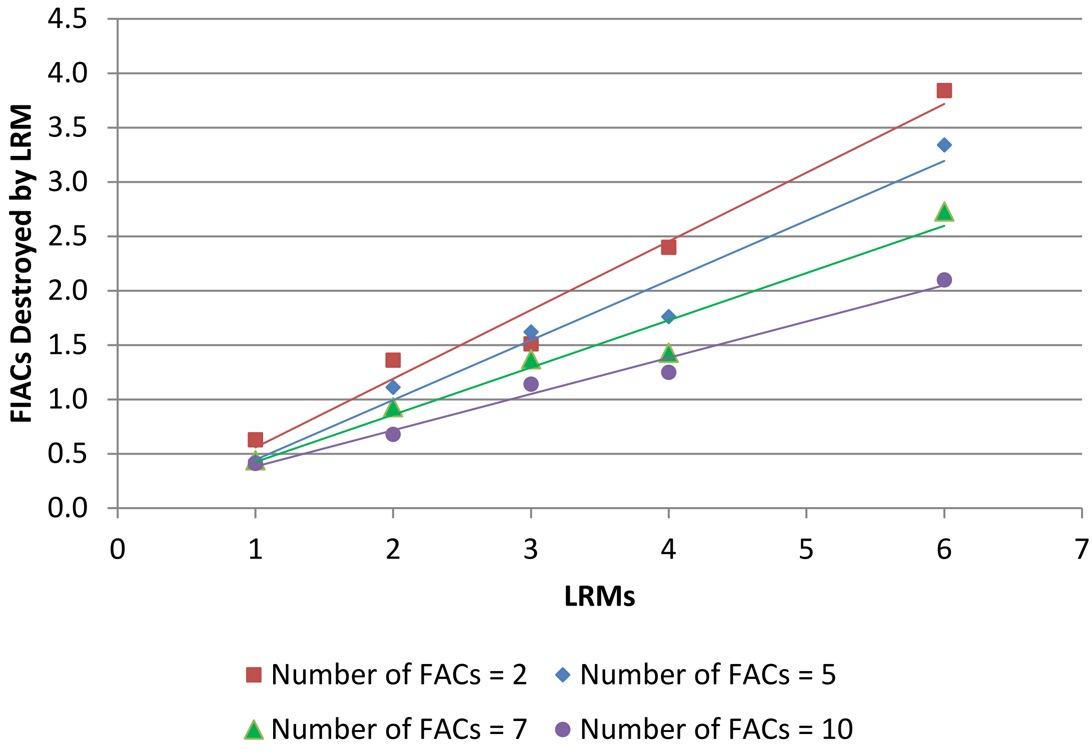

Figure 12. FIACs Destroyed by LRMs

Rerunning all the simulation scenarios with the model redefined to reserve all LRMs for FACs yields the results shown in Table 12.

Table 12. Results with LRMs Reserved for FACs

Total LRMs in AFP	Threat to the AFP		C-802 Engagements		FACs Destroyed		FIACs Destroyed	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
0	31.2%	15.8%	64.8%	9.8%	8.6%	18.7%	100.0%	0.0%
1	25.3%	13.5%	60.6%	10.1%	25.4%	24.6%	100.0%	0.0%
2	21.2%	15.2%	56.1%	10.0%	40.9%	29.6%	100.0%	0.0%
3	17.3%	13.0%	54.2%	9.6%	50.7%	27.4%	100.0%	0.0%
4	14.4%	13.4%	51.8%	9.3%	58.2%	27.6%	100.0%	0.0%
6	11.7%	9.1%	50.0%	7.6%	66.1%	23.6%	100.0%	0.0%

By reserving all LRMs for FACs, the threats to the AFP decreases an additional 4.8%, the C-802 engagements decreases an additional 5.2%, and the FACs destroyed increases an additional 15.7% when the AFP has a total of four LRMs on MH-60S aircraft. Reserving all LRMs for FACs also shows threats to AFP decrease to 11.7%, the C-802 engagements decrease to 50.0%, and the FACs destroyed increase to 66.1% when the AFP has a total of six LRMs on MH-60S aircraft. A summary of the total changes from the baseline results for both six and four LRMs are shown in Table 13.

Table 13. Total Changes from the Baseline

	Six LRMs		**Four LRMs**	
	Mean	**Std Dev**	**Mean**	**Std Dev**
Threat to the AFP	-19.5%	-6.7%	-16.8	-2.4
C-802 Engagements	-14.8%	-2.2%	-13.0	-0.5
FACs Destroyed	+57.5%	+4.9%	+49.6	+8.9

The results for FIACs destroyed remains at 100.0% for all possible scenarios; therefore, the results for the number of FIACs will not be considered any further in the analysis.

Although the average threat to the AFP showed an improvement with the addition of six LRMs when all LRMs were reserved for FACs, the decrease in total threats was only 2.7%. To better understand the impact of adding LRMs, the average threat to the AFP, number of C-802 engagements, and number of FACs destroyed were calculated for each possible number of FACs and LRMs. Figures 13, 14, and 15 show that as the number of FACs increase, the impact of each additional LRM also increases.

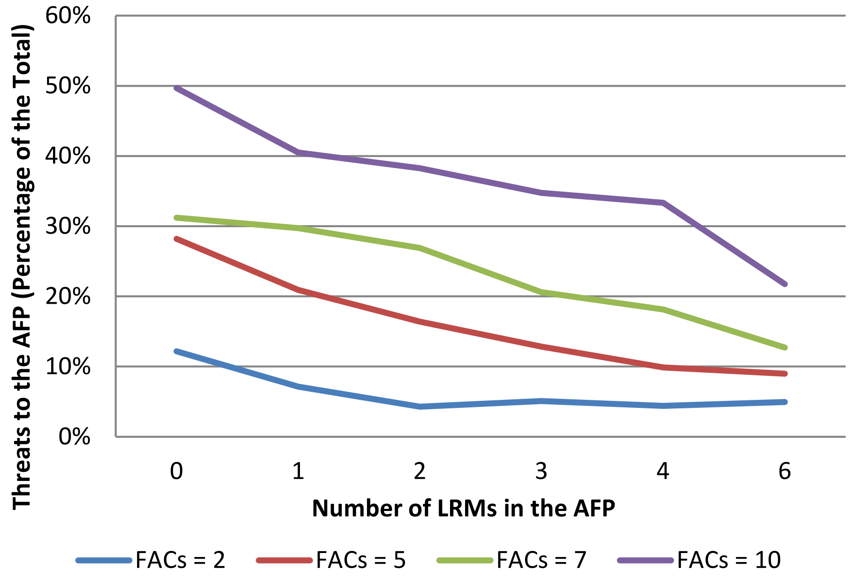

Figure 13. Threats to the AFP with LRMs Reserved for FACs

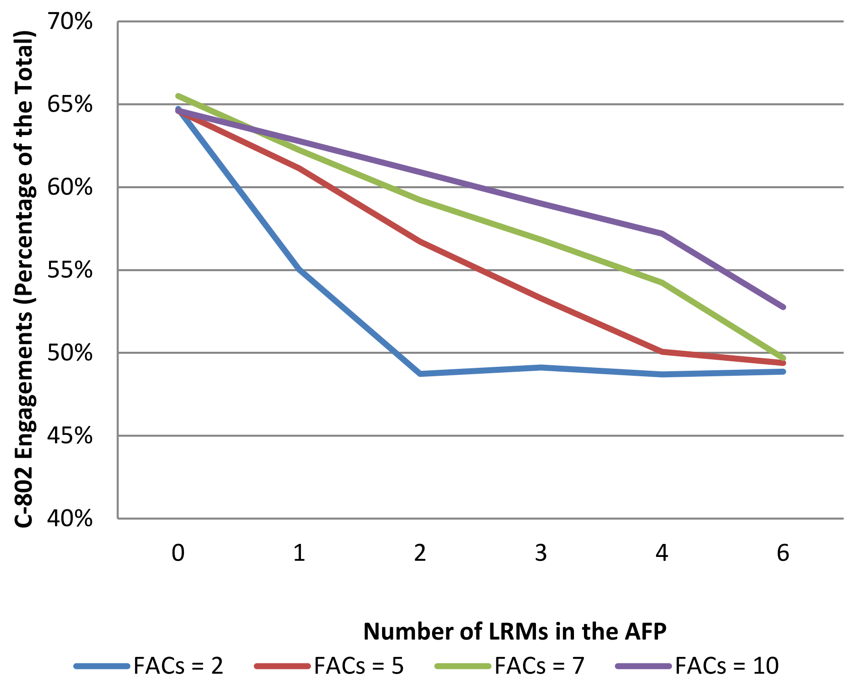

Figure 14. C-802 Engagements with LRMs Reserved for FACs

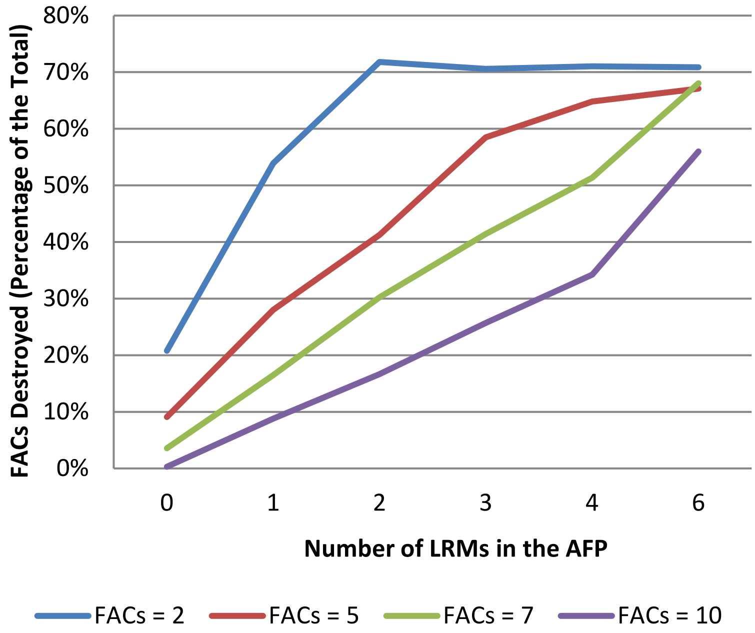

Figure 15. FACs Destroyed with LRMs Reserved for FACs

Partition trees were developed using JMP 13 to determine the best split depending on the number of LRMs and the number of FACs. Figure 16 is a simplified partition tree for threats to the AFP. The Appendix shows detailed partition trees for each of the responses. The partition trees show that the split is between five and seven FACs and four and six total LRMs. If the enemy deploys five or fewer FACs, a total of four LRMs is sufficient for the AFP to defend itself. If the enemy employs more than five FACs against the AFP, then a total of six LRMs is required for the AFP to best defend itself. In order to employ four LRMs, the AFP must equip either three aircraft (one MH-60S aircraft with two LRMs and two MH-60S aircraft each with a mixed loadout) or two aircraft (two MH-60S aircraft each with two LRMs). The mission scenario will provide the information to determine if equipping two or three MH-60S aircraft for a total of four LRMs is the best option to defend the AFP. If a total of six LRMs are employed by the AFP, three MH-60S aircraft are required to carry a load of two LRMs each.

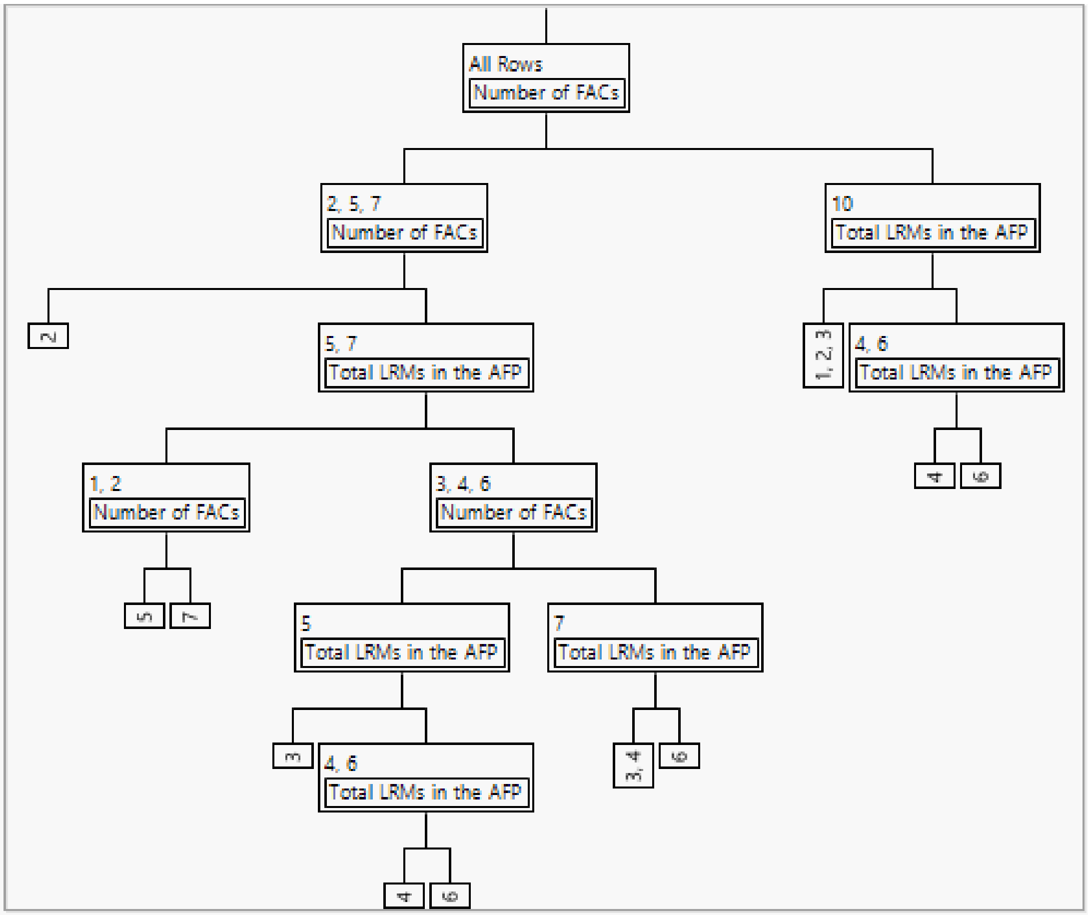

Figure 16. Simplified Partition Tree for Threats to the AFP

C. DESCRIPTION OF ALTERNATIVES

To evaluate the current trade space of long-range ASuW weapons that can be added to the MH-60S, an analysis of alternatives (AoA) was completed to determine the range of solutions with similar capabilities to the LRM that was represented in the simulation model. None of these variants was specifically simulated in the project model due to the low R^2 in the regression analysis of LRM capabilities. This low R^2 value indicates that LRM capability values were not significant in the simulation, so no useful conclusions could be drawn by additional runs of the model. This led to a simple AoA that compared operationally significant capability parameters to what was used in the project model. This analysis defined the trade space of available missiles as the overall weight of the missile, the maximum missile range, and warhead weight. The reference points for all missile capabilities were based on the NSM as shown in Figure 3. Although an initial fit check was completed for the NSM on the MH-60S by NAVAIR, the goal of this analysis was to investigate possible alternatives with capabilities that were near what the NSM offers. The team researched open source material to identify existing weapon systems with similar attributes to that of the NSM and the results of that research are shown in Table 14. Based on Table 14, the solutions that provided similar range capability without adding significant weight to the helicopter were the Turkish SOM-A and the Israeli Delilah HL. Other options such as the AGM-84K SLAM-ER and AGM-158C LRASM can provide further range than the NSM, but they are significantly heavier. A structural analysis would need to be performed to determine if either the NSM-similar missiles or the heavier, longer-range weapons could be deployed on the MH-60S. It should be noted that no other BLOS missiles have been fit checked on the MH-60S, and some are currently only launched from fixed-wing aircraft, which have a much higher payload capacity. If alternatives besides the NSM are desired, further integration and stakeholder analysis would be required to determine the optimum range and other capabilities required for the MH-60S ASuW mission in a DMO environment. Due to the unclassified nature of the research, the team did not have access to, nor did they include, any developmental programs that may better suit the needs of the combatant commanders with a BLOS solution for the ASuW primary mission area.

Table 14. Available LRMs (Continued on Next Page)

Name	Weight (Kg)	Delta from Baseline (kg)	Warhead (Kg)	Range (km)	Delta from Baseline (km)	Country
Naval Strike Missile (NSM) (baseline)	407	0	120	200	0	Norway
AS 15TT	100	-307	30	17	-183	France

Table 14 (Continued)

Name	Weight (Kg)	Delta from Baseline (kg)	Warhead (Kg)	Range (km)	Delta from Baseline (km)	Country
SPEAR Cap 3	100	-307	unknown	120	-80	United Kingdom
Sea Venom	110	-297	30	25	-175	United Kingdom/France
Sea Skua	147	-260	30	20	-180	United Kingdom
Delilah HL	230	-177	30	250	50	Israel
Marte ER	315	-92	70	100	-100	Italy
Penguin MK 3 (AGM-119A)	370	-37	130	55	-145	Norway
SOM-A	600	193	230	250	50	Turkey
Exocet AM39	670	263	165	70	-130	France
AGM-84K SLAM-ER	668	261	247	280	80	United States
RBS-15ER	600	193	200	200	0	Sweden
XASM-3	900	493	unknown	200	0	Japan
AGM-158C LRASM	1250	843	455	926	726	United States

Sources: Data from Jane’s by IHS Markit 2007; Jane’s by IHS Markit 2017a, b, c, d; Jane’s by IHS Markit 2018a, b, c, d, e, f, g, h, j; Kongsberg Defense Systems 2017.

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V. CONCLUSION

A. SIGNIFICANT FINDINGS

The purpose of this capstone project was to determine the benefit to the DMO of providing the MH-60S fleet with a long-range standoff weapon capability and to determine the feasibility of integrating a BLOS ASuW weapon system onto the MH-60S. Using a simulation model and experimentation, this project placed the MH-60S in future scenarios to examine factors that would affect relevant measures of the system's performance, and to determine the capabilities required of that weapon system by answering the five project questions. First, the team determined the USN can equip the MH-60S aircraft with LRMs and begin engaging the enemy earlier when compared to the baseline allowing the MH-60S greater capacity in DMO for ASuW missions. The analysis shows that the addition of the LRM to the MH-60S significantly decreases the threats to the AFP. Table 13 identifies the effect of the LRM against the percentage of threats to the AFP, percentage of C-802 engagements, percentage of FACs and percentage of FIACs destroyed when LRMs are reserved for FACs. Threats to the AFP are decreased by a maximum of 19.5% and enemy C-802 engagements are decreased by a maximum of 14.8%.

This capstone project also studied the current trade space of long-range ASuW weapons that can be added to the MH-60S to affect the DMO environment. The regression analysis used for this project indicates that the capabilities of the LRM are not a significant factor to the threat to the AFP or the enemy C-802 engagements for this model. The maximum and minimum ranges affected only the engagement envelope. Since the LRM can engage up to the engagement range of the FAC in the DOE, modifying maximum range was not required by this capstone project. The minimum engagement range was not an issue due to the LRMs being expended prior the target entering the minimum engagement range. Varying LRM Phit did not affect the number of FACs or FIACs destroyed in the model, and LRM velocity affected engagement timelines, but not the amount of LRMs expended. This capstone identified alternative LRMs that could be evaluated for use on the MH-60S during another research effort. Several alternates are listed in Table 14.

The overall operational effectiveness of the MH-60S fleet is improved by the addition of the LRM. The specific increase in effectiveness is directly dependent upon the number of LRMs in the fleet and the number of FACs attacking the AFP. The partition tree in Figure 16 shows that the split is between five and seven FACs and four and six total LRMs. If the enemy deploys five or fewer FACs, a total of four LRMs is sufficient for the AFP to defend itself. If the enemy employs more than five FACs against the AFP, then a total of six LRMs is required for the AFP to best defend itself.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

While the data and analysis clearly show that the addition of LRMs to the MH-60S in DMO leads to an increase in overall effectiveness, the assumptions used present a challenge. They make it difficult to use the information in this report solely for strategic decisions on force alignments for strike group or AFP planning. Some of the most significant assumptions deal with the optimal performance and 100% availability of major supporting systems in the AFP, including datalink communications and target detection, classification and designation. The variables associated with these systems were included in the ExtendSim model but remained static, so their impacts on the LRM capability are not fully understood. The impacts of these support systems should be investigated further before making any decision on which LRM solution, if any, should be fielded.

The LRM is a BLOS weapon that requires a data link that can transmit detailed information, including tracking and guidance, to the aircraft and subsequently to the missile before it is fired and during flight. The assumption for this project was that this datalink was always available, which is not realistic, but is essential to purely study the effects of adding the LRM capability to the MH-60S fleet. Further analysis is required to understand the impacts of data link communications with the MH-60S and any ASuW weaponry (if in-flight updates are supported) to ensure the LRM has the data it needs to be effective and suitable.

The MH-60S LRM capability relies entirely on another ISR platform for target detection, tracking, and designation, which was assumed to have an A_o of 100%. This project assumed this support came from a MH-60R or other ISR platforms supporting the

AFP. Further research is required to understand these parameters in terms of data quantity, transmission time, and signal quality to ensure the LRM always has this critical support for target detection, tracking and designation. The addition of unmanned aerial vehicles to the AFP construct as an additional ISR support should also be considered and analyzed.

Due to the unclassified nature of the research, the team did not have access to, nor did they include, any developmental programs that may better suit the needs of the combatant commanders with a BLOS solution for the ASuW primary mission area. Future research should evaluate and identify any developmental missile programs that could provide the MH-60S with a long-range capability. A structural analysis, weight and balance analysis, and updated flight envelope need to be performed to determine if any of the long-range missiles can be integrated on the MH-60S.

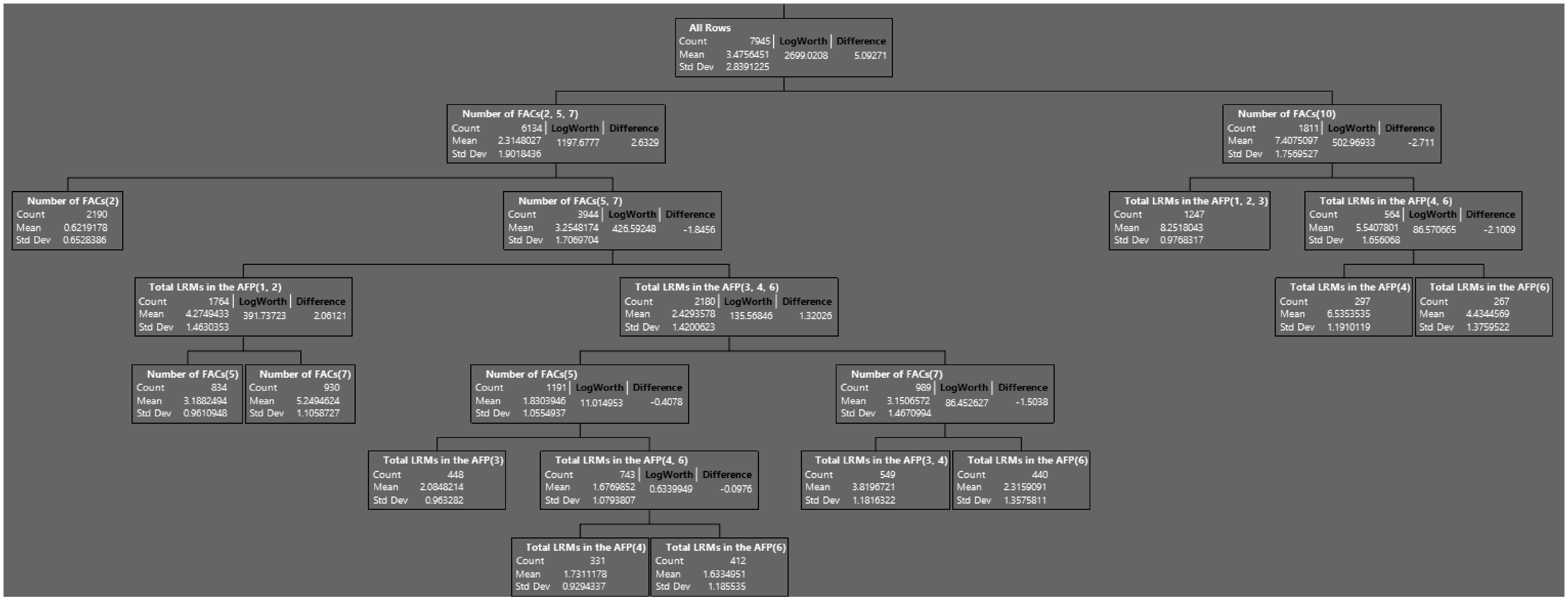
High-level cost impacts should be evaluated to best determine the cost-effectiveness of implementing and supporting the recommended scenario in Chapter IV. A probabilistic distribution of costs should be developed and evaluated against the total life-cycle cost and the associated cost risk. Finally, a determination should be made as to what long-range ASuW weapon systems could the MH-60S utilize. Many weapon options are available; however, the AoA revealed that only three are feasible for consideration when maximum range is the primary consideration: the Norwegian NSM, Turkish SOM-A, and the Israeli Delilah HL. Further analysis is required to determine suitability for use on the MH-60S in a BLOS ASuW role for the Turkish SOM-A and the Israeli Delilah HL based on the size and weight of both missiles.

This project did not factor in the required non-materiel support the LRM would need to be effective and suitable. The costs and feasibility of implementing the required "doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy" (DOTmLPF-P) (Defense Acquisition University 2018, under "General Information/Narrative") support should be weighed against the results of increased operational performance. Manpower analyses should also be conducted for operators and maintainers operating and supporting the LRM as well as the BLOS capability.

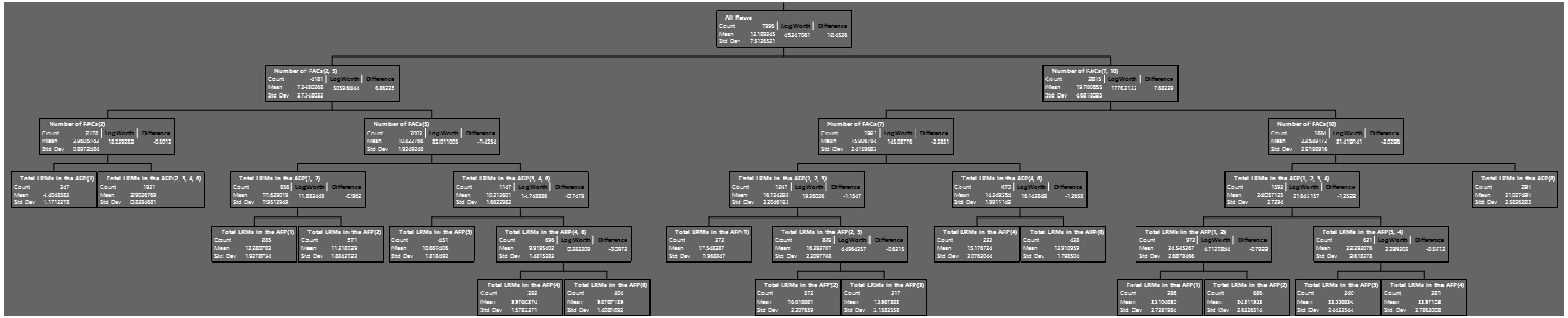
The implementation of an LRM onto an MH-60S should also be analyzed from a DOTmLPF-P perspective. This analysis will assist in determining the second and third order effects of adding an LRM to the MH-60S across the spectrum of personnel, logistics, and resource areas. A more detailed threat analysis should be performed to assess the risks to the AFP from the enemy in terms of the number of enemy FACs deployed and the possible directions of incoming threats. These risks should be evaluated in terms of probability to occur and consequences to the AFP. The consequences are the threat to the AFP and C-802 engagements. This will help determine the required mission scenario for combatting the enemy.

APPENDIX. PARTITION TREES

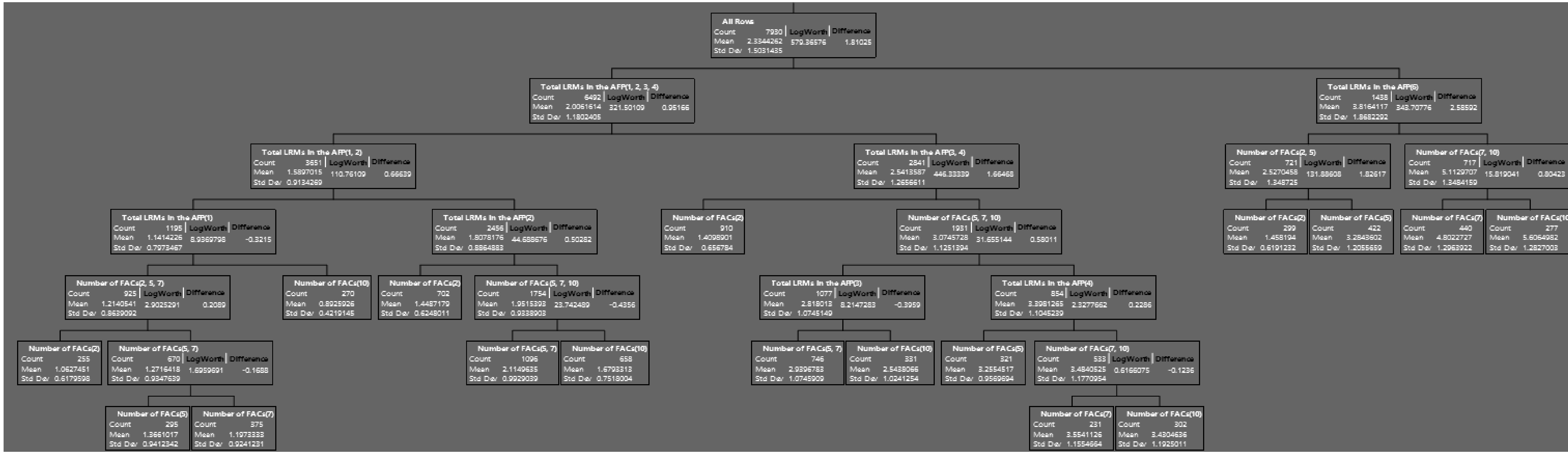
A. THREATS TO THE AFP



B. C-802 ENGAGEMENTS



C. FACS DESTROYED



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